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Natural Resource Stewardship and Science

Protocol Narrative for Nearshore Marine Ecosystem Monitoring in the Gulf of Alaska

Version 1.1

Natural Resource Report NPS/SWAN/NRR—2014/756

ON THE COVER
Herring Bay, Prince William Sound
Photograph by: T.A. Dean

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Natural Resource Report NPS/SWAN/NRR—2014/756

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Revision History Log

All edits and amendments made to this document since its inception should be recorded in the table below. Users of this protocol should promptly notify the project leader of the marine nearshore monitoring program of recommended edits or changes. The project leader will review and incorporate suggested changes as necessary, record these changes in the revision history log, and modify the date and version number on the title page of this document to reflect these changes.

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Add rows as needed for each change or set of changes associated with each version.

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Executive Summary

This document provides a comprehensive plan for long-term monitoring of nearshore marine resources in the Gulf of Alaska (GOA). The project is funded by the National Park Service's (NPS) Southwest Alaska Network (SWAN) and the Exxon Valdez Oil Spill Trustee Council (EVOS) Gulf Watch Alaska (GWA) programs. The objective of this plan is to assist managers in preserving nearshore resources by documenting changes to these resources over time and suggesting possible causes for these changes. The monitoring encompasses all major elements of the nearshore trophic web, from primary producers to apex predators, and focuses on six vital signs: kelp and seagrasses, marine intertidal invertebrates, marine birds, black oystercatchers, sea otters, and marine water chemistry and quality. Sampling will be conducted in Katmai National Park and Preserve (KATM), Kenai Fjords National Park (KEFJ), Prince William Sound (PWS) and to a lesser extent on the Lake Clark National Park and Preserve (LACL). Related projects that provide similar data from Kachemak Bay, Cook Inlet are not included here. Trends in different vital sign metrics (e.g. the number of sea otters) will be examined and the variation in the relative extent of change among different locations will be assessed.

Sampling will focus on estimating: cover by eelgrass and kelp; abundance (percent cover or density) of intertidal algae and invertebrates on sheltered rocky shores; density of infaunal invertebrates in gravel / mixed-sand gravel shores; size and density of Pacific blue mussels in mussel beds; abundance of marine birds; abundance, nest site density, and composition of prey provisioned to chicks for black oystercatchers; abundance, survival and diet of sea otters; and concentration of various organic and inorganic contaminants in mussels. In addition, temperature (both water and air) and salinity will be measured. All of these metrics will be examined within each of three core areas: KATM and KEFJ, and Western Prince William Sound (WPWS). Sampling within these core areas will generally be done at a frequency of once per year. Additionally, selected metrics will be examined less frequently in Eastern and Northern PWS (EPWS and NPWS) and LACL. Sampling of most metrics will be focused on randomly selected locations within each region.

Generalized guidelines on analytical methods to be used to detect trends in various vital sign metrics are provided. Also given are preliminary estimates of the extent of change that is deemed ecologically important and might trigger management action. In addition, guidelines for data management, management structure, operational requirements, and costs are provided.

Acknowledgments

The National Park Service, the Exxon Valdez Oil Spill Trustee Council, and the US Geological Survey supported this work. Special thanks to the NPS staff, and especially, Michael Shephard, Alan Bennett, Dorothy Mortenson, and Bill Thompson for their support and valued review comments. We would also like to thank Jim Estes and Kim Trust for their reviews.

1 Purpose and Background

1.1 Introduction

The purpose of this protocol is to provide a comprehensive plan to be used in implementing a long-term monitoring program of nearshore resources in the Gulf of Alaska (GOA). The goals of this program are to detect changes that may occur within the GOA nearshore system over the next several decades, to help identify potential causes for change, and to provide this information to resource managers and to the public in order in preserve nearshore resources. This protocol narrative provides an overview of design elements and procedures to be used in implementation of the protocol. Specifically, it provides:

- Background and rationale for marine nearshore monitoring
- A sampling design with rationale for its selection
- Metrics selected for sampling
- Specific sites to be used in sampling
- Proposed frequency of sampling and a proposed master schedule for plan implementation
- A structure for a database management system to be used in the nearshore
- Proposed guidelines for analysis of the data
- Proposed guidelines and schedules for review and modification of the design over time
- Estimated costs associated with implementation of the design

Details on how all aspects of the components described in the narrative will be carried out are provided in a series of Standard Operating Procedures (SOPs) provided in separate documents. Both this Protocol Narrative and SOPs were developed using guidelines established in Oakley et al. (2003).

1.2 Rationale for monitoring in the nearshore

The nearshore can be defined as that section of the marine ecosystem that extends from the high tide line, offshore to depths of about 20 m. The nearshore is considered an important component of the system because it provides:

- A variety of unique habitats for resident organisms (e.g. sea otters, harbor seals, shorebirds, seabirds, nearshore fishes, kelps, seagrasses, clams, mussels, and sea stars).
- Nursery grounds for marine animals from other habitats (e.g. crabs, salmon, herring, and seabirds).
- Feeding grounds for important consumers, including, killer whales, harbor seals, sea otters, sea lions, sea ducks, shorebirds, brown bears, and many fishes and shellfish.
- A source of animals important to commercial and subsistence harvests (e.g. marine mammals, fishes, crabs, mussels, clams, chitons, and octopus).

- An important site of recreational activities including fishing, boating, camping, and nature viewing.
- A source of primary production for export to adjacent habitats (primarily by kelps, other seaweeds, and eelgrass).
- An important triple interface between air, land and sea that provides linkages for transfer of water, nutrients, and species between watersheds and offshore habitats.

In addition, the nearshore is broadly recognized as highly susceptible and sensitive to a variety of both natural and human disturbances on a variety of temporal and spatial scales (Reviewed in Valiela 2006, Bennett et al. 2006, Dean and Bodkin 2006). For example, observed changes in nearshore systems have been attributed to such diverse causes as global climate change (e.g. Barry et al. 1995, Sagarin et al. 1999), earthquakes (e.g.

Baxter 1971), oil spills (e.g. Peterson 2001, Peterson et al. 2003), human disturbance and removals (e.g. Schiel and Taylor 1999), and influences of invasive species (e.g. Jamieson et al. 1998). Nearshore systems are especially good indicators of change because many of the organisms in the nearshore are relatively sedentary, accessible, and manipulable (e.g. Dayton 1971, Sousa 1979, Peterson 1993, Lewis 1996). Also, in contrast to other marine habitats, there is a comparatively thorough understanding of mechanistic links between species and their physical environment (e.g. Connell 1972, Paine 1974, 1977, Estes et al. 1998) that facilitates understanding causes for change. Lastly, the nearshore is the one habitat within which it is most likely that we will be able to detect relatively localized sources of change, tease apart human induced from naturally induced changes and, provide suggestions for management actions to reduce human induced impacts. Because many of the organisms in the nearshore are sessile or have relatively limited home ranges, they can be geographically linked to sources of change with a reasonable degree of accuracy.

1.3 Description of the GOA nearshore system

The following is a brief description of the nearshore system in the GOA. It is intended to provide an overview of what is generally perceived as important components and attributes of the system in order to provide background and context for sections that follow. More detailed descriptions of the GOA nearshore can be found in other more comprehensive resources (Peterson 2001, Mundy 2005).

The nearshore can be defined as that section of the marine ecosystem that extends from the high tide line, offshore to depths of about 20 m. It can be divided into the intertidal zone (between high-high water and lower-low water) and the nearshore subtidal (from lower-low water to depths of 20 m). The intertidal shorelines are geomorphologically diverse and vary from sheltered marshlands and beaches to steep rocky outcroppings subjected to high waves. The subtidal zone is a mix of cobble/ gravel, rocky outcroppings, and sand/silt. The subtidal substrate composition is only loosely correlated with that observed in adjacent intertidal zones.

Probably the most well recognized members of the nearshore habitat are the large mobile predators that reside in or spend some critical phase of their lifecycle within the nearshore zone. These include a variety of mammals (both terrestrial and marine), birds, and fishes. Among the most conspicuous marine mammals are sea otters, river otters, sea lions, and harbor seals (Lowry and Bodkin 2005). Sea otters spend their entire life cycle principally within the nearshore zone and rely on intertidal and nearshore subtidal invertebrates (primarily clams and mussels) for food. River otters live and feed almost exclusively on nearshore fishes and invertebrates for food. In contrast, sea lions and seals are common inhabitants of the nearshore zone, but rely primarily on more pelagically derived sources for food (primarily pollock and fishes associated with more offshore environments). Terrestrial mammals including black and brown bears and deer occasionally forage in the intertidal. Birds commonly encountered include eagles, gulls, shorebirds, seabirds, and seaducks (Irons et al. 2000). Among those most closely linked to the nearshore are the black oystercatcher and several sea ducks (harlequin ducks and Barrows goldeneye) (Andres and DeZeeuw 1991, Robertson and Goudie 1999, Vermeer 1982, 1983, O'Clair and O'Clair 1998). Black oyster catchers are year-round residents that breed and rear young in the habitats adjacent to the nearshore and feed almost exclusively on intertidal mussels, limpets, and chitons. Harlequin ducks and Barrows goldeneye breed and nest in more upland habitats, but congregate in large numbers in the GOA nearshore (especially in winter) where they feed on mussels and other smaller epibenthic invertebrates in the intertidal and shallow subtidal zones. Pigeon guillemots breed on nearby offshore islands or on cliff faces and rely to a small extent on nearshore fishes for food. Other birds species (e.g. bald eagles, Northwestern crows, kittiwakes, and glaucous winged gulls) often feed in the nearshore, but rely more heavily on food resources derived from either terrestrial, watershed, or offshore sources (e.g. carrion from mammals, salmon, or pelagic forage fishes) (O'Clair and O'Clair 1998). Several commercially valuable fishes including Pacific halibut and salmon also rely on the nearshore. Halibut occasionally come to shallow water to feed on salmon and crabs. Some pink salmon lay eggs in the intertidal zone and both pink and Chum salmon rely on nearshore resources as food and shelter during outmigration (Simenstead et al.1980).

The important birds, mammals, and fishes represented in the nearshore, rely on a variety of habitats and species for critical life functions. Those habitats and assemblages of species are described as follows. The intertidal community on sheltered rocky shorelines is generally divided into three or four relatively distinct vertical zones characterized by different plant and invertebrate assemblages (Nybakken 1969, Feder and Kaiser 1980, O'Clair and Zimmerman 1986, Highsmith et al. 1994). The vertical extent, position with respect to tidal elevation, and species composition of each zone varies with physical characteristics of the site (e.g. substrate composition, slope, tidal range, and relative exposure) but can generally be characterized as follows. The upper zone is dominated by barnacles and generally occurs over a tidal range extending from about the mean tide level to mean high water (approximately plus 1 to plus 2 m, MLLW). It is bounded at the upper elevation by a thin crust of the black lichen *Verrucaria* spp. This zone generally has lower cover and a fewer number of species than the lower zones. Dominant organisms include barnacles (*Chthamalus dalli*, *Semibalanus balanoides*, and *Balanus glandula*), littorine snails (*Littorina scutulata* and *Littorina sitkana*), limpets (*Lottia pelta* and *Lottia persona*), and mussels (*Mytilus trossulus*). The next lower zone is dominated by *Fucus distichus* and generally extends from the mean tide level to just above mean lower-low-water (approximately plus 1 to plus 0.3 m, MLLW). The zone includes various algae (brown algae, *Fucus distichus* and *Pilayella* spp.; green algae, *Ulva* and *Cladophora* spp.; red algae *Palmaria*, *Neorhodomela* and *Odonthalia* spp.) as well as many of the same invertebrates as observed as dominant in the barnacle zone (e.g. barnacles, mussels, littorine snails, and limpets). On slightly more exposed sites, a narrow red algal zone is often seen just below the *Fucus* zone. This zone is dominated by various types of red algae, especially *Palmaria, Halosachion* and

Cryptosiphonia spp. This zone is less distinguishable at more sheltered sites where there is little wave action. The lower intertidal (generally below MLLW) is dominated by kelps (e.g. *Laminaria* spp.) or eelgrass (*Zostera marina*) and often extends into the subtidal zone.

Larger predatory invertebrates common in the intertidal include seastars (*Pycnopodia helianthoides*, *Pisaster ochraceus*, and *Evasterias troschelii*) and snails (*Nucella* spp. and *Lirabuccinum dirum*) that feed on barnacles, mussels, limpets, and littorines. Because these habitats are often exposed to the air, fish are relatively rare. However, several species of fish including the high cockscomb (*Anoplarchus purpurescens*) and the crescent gunnel *(Pholis laeta*) are commonly found under cobbles or boulders. In addition, Pacific Herring (*Clupea pallasil*) utilize the rocky intertidal as spawning habitat and in some localities deposit eggs in spring to create dense mats of eggs over several kilometers of shoreline.

In soft sediment intertidal habitats there are fewer conspicuous algae or invertebrates on the surface as most of the organisms are infaunal (buried below the surface). These infaunal communities are dominated by a variety of clams, small snails, annelid worms, and a variety of small crustaceans (primarily amphipods) (Feder and Keiser 1980, Driskell et al. 1996). Among the most abundant organisms (in terms of biomass) are littleneck clams (*Leukoma staminea*), butter clams (*Saxidomus gigantea*), *Macoma* spp., and cockles (*Clinocardium nuttallii*). Several clams (especially littleneck clams) are important subsistence foods and are also commercially harvested.

The subtidal zone is generally heavily vegetated by either kelps or eelgrass. Rocky bottoms are dominated by kelps including *Laminaria* spp., *Agarum clathratum*, and at more exposed shorelines *Nereocystis luetkeana* (Rosenthal et al. 1977, Dean et al. 1996a, 1996b). These kelps provide substrate for a variety of sessile invertebrates and a habitat for small crustaceans. Among the most common sessile invertebrates are bryozoans, hydroids, and the small mussel *Musculus* spp. The surfaces of rocks under the kelps are generally covered with coralline algae, fleshy red algae, and sessile invertebrates (bryozoans, sponges, and hydroids). The algae and sessile invertebrates harbor a rich fauna dominated by small crustaceans (shrimp and amphipods). These rock dominated communities are home to a variety of larger epibenthic invertebrates including several sea stars (e.g. *Pycnopodia helianthoides*, *Dermasterias imbricata*, *Evasterias troschelii*, and *Orthasterias koehleri*), crabs (especially the helmet crab, *Telmessus cheiragonus*), and sea urchins (*Strongylocentrotus droebachiensis*). Fishes common on rocky bottoms include greenlings (*Hexagrammos* spp.), a variety of sculpins, pricklebacks (especially *Stichaeus punctatus*), and juvenile Pacific cod (*Gadus macrocephalus*) (Rosenthal et al 1980, Dean et al. 2000). Along shorelines where herring spawn, eggs are often deposited on a variety of subtidal substrates to depths of several meters. A variety of rockfishes are also common along more exposed shorelines. While the seafloor is predominantly covered by rock in these habitats, there are often small patches of sand or silt interspersed that harbor a rich infaunal community including a variety of clams, annelid worms, and crustaceans (Dean and Jewett 2001).

Soft bottom subtidal habitats are often vegetated by dense stands of eelgrass (*Zostera marina*) (McRoy 1968, 1970, Rosenthal et al 1977, Dean et al. 1998). These are most common in relatively sheltered embayments fed by streams that supply silt, nutrients, and detritus. The eelgrass bed provides a substrate for a rich epifaunal community including small mussels (*Musculus* spp.) hydroids, and bryozoans (Rosenthal et al. 1977, Jewett and Dean 1977). Small crustaceans and a variety of small snails are also commonly associated with eelgrass. Small harpacticoid copepods are particularly important as a food for outmigrating salmon fry and are very abundant within the eelgrass community. The community of large epibenthic invertebrates and fishes are less diverse than on rocky bottoms, but high densities of the sea stars (*Pycnopodia helianthoides* and *Dermasterias imbricata*), as well as helmet crabs (*Telmessus cheiragonus*) are often found in eelgrass beds (Rosenthal et al 1977, Dean et al. 1996b). Common fishes include cod, greenlings, and gunnels (Dean et al 2000). Juvenile Pacific cod (*Gadus macrocephalus*) are especially abundant. Herring utilize eelgrass as substrate to deposit eggs and in addition sandlance burrow into soft sediments in the nearshore subtidal (and lower intertidal) and both sandlance and capelin deposit eggs in the nearshore soft-bottom habitats (Robards et al. 1999). The infaunal community in eelgrass beds and in other soft sediment subtidal habitats is characterized by a diverse assemblage of small crustaceans, annelids, and gastropods (Feder and Jewett 1987, Jewett et al. 1999, Dean and Jewett 2001).

The food web in the nearshore system of the GOA is relatively complex (Figure 1). Most of the animals derive a large proportion of their energy from sources that can be traced to benthic based primary production from seaweeds (especially kelps), eelgrass, and unicellular algae (especially benthic diatoms). Some energy is also derived from offshore planktonic sources. Plankton and nearshore derived detritus are utilized as food by a large suite of filter and suspension feeding benthic invertebrates including clams, mussels, and barnacles as well as some crabs (especially hermit crabs). Other benthic invertebrates are herbivorous and feed primarily on diatoms or small encrusting algae (e.g. limpets, littorines, and some crabs) or larger seaweeds and eelgrass (e.g. sea urchins, helmet crabs, and some larger herbivorous snails). The predators comprise a large and diverse group that include sea stars, predatory snails, fishes, birds, sea otters, river otters, harbor seals and occasionally killer whales. Sea stars including *Pycnopodia helianthoides*, *Pisaster ochraceus*, *Evasterias troschelii*, and *Leptasterias epichlora*, feed primarily on barnacles, mussels, small snails, and clams.

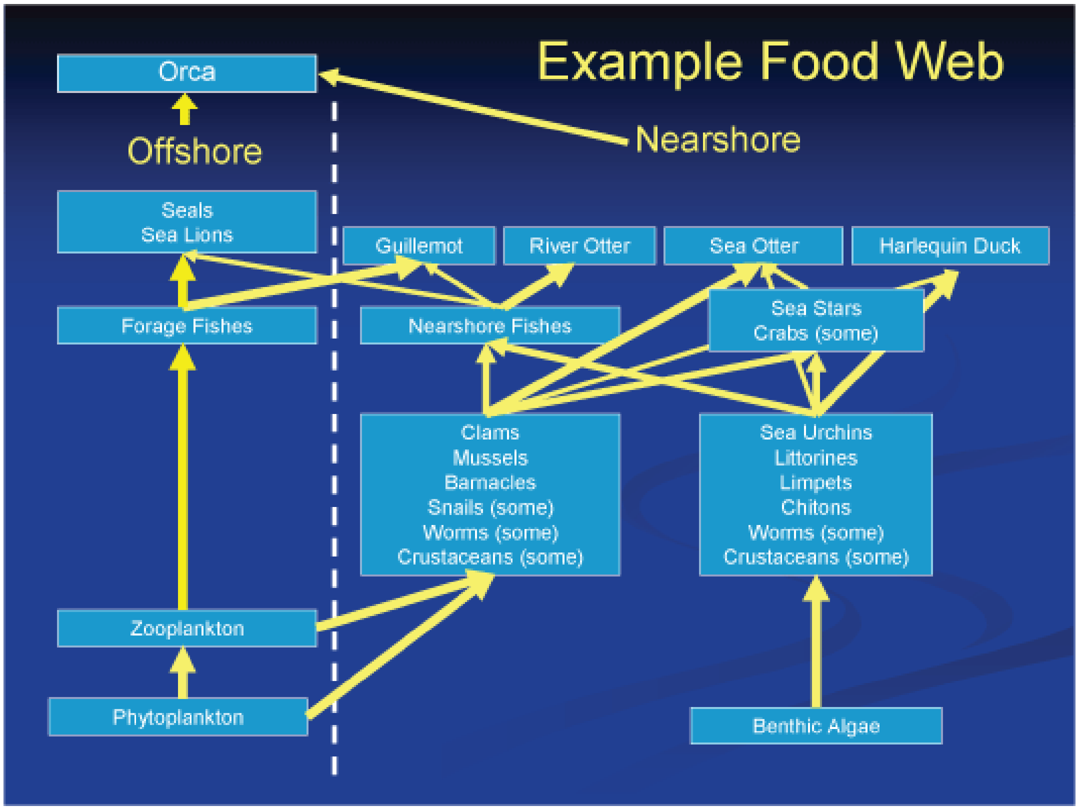

Figure 1. Simplified example of the food web for the nearshore Gulf of Alaska. The width of arrows indicates the degree of dependence on a particular food source. Also shown are links to offshore food.

The structure of algal and invertebrate communities of the nearshore GOA is largely governed by the same forces widely recognized as controlling the distribution and abundance of organisms in the more widely studied temperate rocky shores (reviewed in Peterson 2005). Important physical factors determining distribution and abundance include substrate composition, slope, temperature (both water and air), desiccation (for the intertidal), light, exposure to waves, the degree of fresh water input (i.e. salinity), currents, and ice scour. It is generally accepted that physical factors tend to limit the upper distribution of species in the rocky intertidal zone, and are generally more important higher in the intertidal. As one proceeds down slope to the lower intertidal and subtidal zones, the extremes in the physical environment generally diminish (i.e. less extreme variation in temperature and degree of desiccation, less influence of ice scour). As a result, biological processes (competition and predation) become increasingly more important with depth. In the absence of physical disturbance or predation, competition for space generally leads to dominance by one or a few superior competitors. However, predation and intermediate levels of physical disturbance (e.g. moderate ice scour or bashing of the intertidal by floating logs) often reduces competitive pressures and leads to more diverse assemblages. Of particular importance is predation by certain "keystone" predators that prey on potentially dominant species and thereby reduce competitive pressures and exert influence on community structure that is disproportionate to their abundance. In the GOA, keystone predators include sea otters (Estes and Palmisano 1974, Riedman and Estes 1990) certain sea stars (O'Clair and Rice 1985) black oyster catchers, (Power et al. 1996, Marsh 1986) and predatory snails (Carroll and Highsmith 1996). Changes in the abundance of these keystone species can produce intense direct and indirect effects that can cascade through the ecosystem. In one well documented example in Alaska, reduction in sea otters led to an increase in the abundance of herbivorous sea urchins which in turn caused a reduction in the kelp upon which sea urchins graze.

While not well studied, it appears that physical factors are also important in structuring communities in soft bottom habitats as in rocky habitats. Sediment type and salinity have been shown to be key determinants of structure in soft sediment habitats. Predation (especially by sea otters) and competitive interactions are also known to influence soft sediment community structure as well (Kvitek et al.1992).

Variation in the timing and abundance of larvae can also exert a strong influence on benthic community structure in both rocky and soft sediment habitats (Connolly and Roughgarden 1999, Gaines and Roughgarden 1995, Gaines et al. 1995). Many of the sessile invertebrates and some algae rely on larvae or spores transported from distant populations for recruitment. Abundances of larvae are known to be highly variable in both space and time, and in more northerly latitudes like the GOA, can vary greatly from year to year (Estes and Duggins 1995, Connolly et al. 2001). In years when particularly large numbers of recruits are available, increases in abundance of a particular species can overwhelm the influence of predators and lead to larger than normal population sizes. In some cases, the effects of a particularly large year class can persist and have multi-year impacts on local community structure.

Factors structuring communities are often classified as either top down, or bottom up controls (Connolly and Roughgarden 1999). In the nearshore benthic community, the bottom up forces would include variation in larval recruitment and availability of food (for invertebrates) or light and nutrients (for plants). Top down forces include physical disturbance to higher trophic levels or predation. It is clear that in the GOA as elsewhere, both top-down and bottom up forces work to structure nearshore systems.

1.4 Historical causes for change in the GOA nearshore

While history is not necessarily a predictor of future events, it is none the less instructive to gain a historical perspective on changes that have occurred in the nearshore GOA over the past several decades and identify the causes for those changes. There have been three major events that have resulted in long-term change in the nearshore community in the GOA: The extirpation and subsequent re-colonization by sea otters, the 1964 earthquake, and the *Exxon Valdez* oil spill. Sea otters in the GOA were hunted to near extinction in the early part of the 20th century, leaving only a few isolated remnant populations. Based on more recent observations of the effects of more localized declines in sea otter abundance (Estes et al. 1998) and on observations of effects of sea otter range expansion (Estes and Palmisano 1974, Kvitek et al. 1992, Trowbridge 1995) it is clear that the near extinction of sea otters a century ago likely caused a dramatic shift in nearshore community structure. Declines in sea otter abundance likely resulted in increases in population densities of major prey items including sea urchins, clams, and crabs. As a result of increased sea urchin abundance, kelps on which sea urchins graze likely decreased in abundance. Since the cessation of large-scale human take of sea otters in the early 20th century, sea otter populations in the GOA have slowly recovered. The recovery has been characterized by decade or longer periods of low sea otter population density followed by relatively rapid increases in population size as the sea otters expanded their range and colonized previously unoccupied habitats. Expansion of sea otters into the Aleutian Islands led to a reduction in sea urchin abundance, an increase in kelp, and an increase in sea urchin predators including Common eiders

(Estes et al 1998). Over the past three decades there were also dramatic increases in number of sea otters in Eastern Prince William Sound (Trowbridge 1995) and Kodiak Island (Kvitek et al. 1992). The expansion of sea otters into new habitats led to rapid localized declines in crab and clam populations, and in PWS led to closure of the commercial crab fishery. Cascading effects on other parts of the system (e.g. a reduction in populations of animals that compete with sea otters for clam and crab resources) likely occurred but were not documented. With the exception of portions of Kodiak Island and Cook Inlet, sea otters now occupy most of the nearshore GOA from the Aleutians to Prince William Sound.

The magnitude 9.2 great Alaska earthquake in 1964 had its epicenter near Perry Island in Northern PWS (NRC 1971). The quake generated a tsunami that resulted in the loss of life and did extensive physical damage to towns and villages that border the Sound. Areas to the south of the epicenter were uplifted, with maximum uplift of nearly 10 m occurring on southwestern portions of Montague Island. Post quake surveys documented the complete destruction of the intertidal community in areas of maximum uplift as the land and associated attached fauna and flora was thrust upward into the supratidal zone (Baxter 1971, Haven 1971, Hubbard 1971). In addition, the quake caused an estimated 35% reduction in intertidal hard-shell clam populations in PWS (Baxter 1971). Other effects resulting from the tsunami, the spilling of fuel and oil from ruptured storage tanks, underwater land slides, the redirection of streams, the blockage of lagoon entrances, and the formation of new intertidal mudflats likely had a profound impact on the nearshore, but these impacts were not well documented. Recovery of some intertidal communities apparently occurred within several years or less, but it was estimated that recovery of some clam populations took considerably longer (Hubbard 1971).

The most recent event resulting in major changes to the nearshore in the GOA was the *Exxon Valdez* oil spill (EVOS). In March 1989, the T/V *Exxon Valdez* ran aground in Prince William Sound (PWS) spilling almost eleven million gallons of crude oil. The oil contaminated nearly 1,500 miles of coastline in the GOA region extending from PWS to Kodiak Island and killed hundreds of thousands of birds, mammals, and untold numbers of fishes and invertebrates (Spies et al. 1996). In addition, the spill and the associated cleanup of shorelines resulted in a major restructuring of the intertidal community. In areas heavily oiled by the spill, reductions of 50% or greater were noted for most of the dominant plants and animals in the mid and upper intertidal zone including barnacles, mussels, limpets, and *Fucus* (Highsmith et al. 1994). Shortly after the spill, the provision of un-colonized substrate led to increases in ephemeral algae that were on the order of 50 to 300%. Changes also occurred within the subtidal zone, where reductions in some crabs, sea stars, and sensitive infaunal organisms (primarily amphipods) were noted along with an increase in more stress tolerant species (Dean et al. 1996b, Jewett et al. 1999, Dean and Jewett 2001). While nearshore communities within much of the spill area recovered within several years, some impacts in heavily oiled portions of PWS persisted for 18 years or more. As of 2002, oil was still present in sediments (Short et al. 2006) and clams (Fukuyama et al. 2000) within the heavily oiled portion of western PWS, and there was evidence for ongoing effects of lingering oil on sea otters, sea ducks, and some fishes (Peterson et al. 2003). Exposure to lingering oil continued through 2005 for Barrow's goldeneyes (Esler et al. 2011) and through at least 2009 for harlequin ducks (Esler et al. 2010). For both sea otters and harlequin ducks, exposure to lingering oil was linked to lower survival rates, as population densities remained suppressed in heavily oiled portions of the Sound through at least 2007 for sea otters (Bodkin et al. 2011, Monson et al. 2011) and 2005 for harlequin ducks (Iverson and Esler 2011).

Over the past several decades there have undoubtedly been additional changes in the nearshore GOA that resulted from both human activities (e.g. logging activity, shoreline development, fishing pressure) and natural events (e.g. climate change associated with changes in the Pacific Decadal Oscillation). However, these have largely gone undocumented in the nearshore. We suspect that many of these changes have been more difficult to detect because they are less episodic in nature, or have occurred over smaller spatial and/or temporal scales than those related to re-colonization by sea otters, earthquakes, or the *Exxon Valdez* oil spill.

2.0 Goals and Sampling Design

2.1 Program goals

The goals of the nearshore monitoring program are to detect change; identify causes of change, and communicate these to the public and to resource managers to preserve nearshore resources. It is not possible to predict what changes might occur within the nearshore zone over the next several decades, and unforeseen changes that result from unforeseen causes, will almost certainly occur. However, hypothesizing what changes may occur, and what temporal and spatial scales they may occur over, is an important initial step in the development of an effective long-term monitoring program. We have developed a list of potential changes to the system based from a review of the changes that have occurred within the GOA over the past several decades, and a review of changes that have occurred in regions outside of Alaska where anthropogenic impacts have been more prevalent (Appendix A). This exercise suggests that changes may result from both natural and anthropogenic agents, and may occur over varying scales of time and space. One of the major challenges is to design a sampling program that can effectively detect changes regardless of their cause and the temporal and spatial scales over which they occur.

The monitoring program described here will focus on the portion of the Gulf of Alaska from Katmai National Park eastward to Prince William Sound. It is designed to detect changes that occur on spatial scales of 10 km of coastline or larger, and on temporal scales of one year or more. It is likely that changes over these scales of space and time will occur as the result of multiple causes. As indicated above, the monitoring program calls for detecting change based on synoptic sampling of a selected set of physical and biological variables (e.g. sea surface temperature or eelgrass distribution) over the entire study region, sampling of a suite of biological and physical parameters within the three core areas, or blocks (KATM, KEFJ, and WPWS), and sampling of a subset of biological and physical parameters throughout the study area on a less frequent basis. Details with respect to metrics sampled, number and location of sampling sites, and frequency of sampling are provided in the sections that follow.

The second goal of the monitoring program is to assign cause. As with most biological systems, changes will likely result from multiple causes and we anticipate that the responses to these will be complex. Most responses are likely to be non-linear and those resulting from multiple causes are likely to be non-additive. As a result, while it is likely that we will be able to suggest that changes are, in part, related to certain causative agents, quantitative assessments (the proportion of observed change attributable to a given cause) will be more difficult.

Possible causes for change will be assigned by first examining the spatial and temporal patterns of change that occur in relation to the expected patterns. For example, changes that occur over large spatial scales might be attributable to large-scale climate changes, but are unlikely to be caused by more localized coastal development. Second, we will conduct concurrent monitoring of biological responses and likely forcing agents. The forcing agents will include both top down (i.e. predators and physical disturbance) and bottom up (food or productivity related) factors. Possible correlations between responses and changes in forcing agents will suggest possible causation.

2.2 Vital sign metrics and objectives

This protocol focuses on sampling of several key members of the nearshore system in the GOA that are both numerically and functionally important to the system's health and on several key environmental drivers. These are termed "vital signs" and include kelps (and other marine algae) and seagrasses, marine intertidal invertebrates, marine birds, black oystercatchers *(Haematopus bachmani*), sea otters (*Enhydra lutris)*, and marine water chemistry and quality. The rationale for focusing on these vital signs is given in Bennett et al. 2006 and is summarized here.

Kelp, other algae, and seagrass are "living habitats" that serve as a nutrient filter, provide understory and habitat for planktivorous fish, clams, urchins, and a physical substrate for other invertebrates and algae. Kelps and other algae are the major primary producers in the marine nearshore and because they are located in shallow water they could be significantly impacted by human activities. These include spills of oil or other contaminants, dredging and disturbance from anchoring of vessels, and increased turbidity caused by runoff of sediments or nutrients.

Marine Intertidal Invertebrates provide critical food resources for shorebirds, ducks, fish, bears, sea otters, and other marine invertebrate predators, as well as spawning and nursery habitats for forage fish and juvenile crustaceans. Benthic invertebrates and algae are ecologically diverse in terms of habitat and trophic requirements; have a wide range of physiological tolerances; are relatively sedentary, and have varied life-histories. As a result, they are good biological indicators of both short-term (e.g. annual) and long-term (e.g. decadal scale) changes in environmental conditions.

Marine Birds are predators near the top of marine nearshore food webs. Marine birds are long-lived, conspicuous, abundant, widespread members of the marine ecosystem and are sensitive to change. Because of these characteristics marine birds are good indicators of change in the marine ecosystem. Many studies have documented that their behavior, diets, productivity, and survival changed when conditions change. Public concern exists for the welfare of seabirds because they are affected by human activities like oil pollution and commercial fishing.

Black Oystercatchers are well suited for inclusion into a long-term monitoring program of nearshore habitats because they are long-lived; reside and rely on intertidal habitats; consume a diet dominated by mussels, limpets, and chitons; and provision chicks near nest sites for extended periods. Additionally, as a conspicuous species sensitive to disturbance, the black oystercatcher would likely serve as a sentinel species in detecting change in nearshore community resulting from human or other disturbances.

Sea Otters are keystone species that can dramatically affect the structure and complexity of their nearshore ecological community. They cause well described top-down cascading effects on community structure by altering abundance of prey (e.g. sea urchins) which can in turn alter abundance of lower trophic levels (e.g. kelps). Sea otters generally have smaller home ranges than other marine mammals; eat large amounts of food; are susceptible to contaminants such as those related to oil spills; and have broad appeal to the public. Recent declines in sea otters have been observed in the Aleutian Islands. Currently declines are documented in areas to the western edge of our study area. As a result of these declines, the Western Alaska stock of sea otters (which includes populations in Katmai National Park and Preserve as well as Aniakchak

National Monument and Preserve), was federally listed as threatened on September 2005 under the Endangered Species Act.

Marine Water Chemistry and Water Quality**,** including temperature and salinity, are critical to intertidal fauna and flora and are likely to be important determinants of both long-term and short-term fluctuations in the intertidal biotic community. Basic water chemistry parameters provide a record of environmental conditions at the time of sampling and are used in assessing the condition of biological assemblages. Water quality (including water temperature, salinity, and levels of contaminants such as heavy metals and organic pollutants) are also critical in structuring nearshore marine ecosystems and can cause both acute and chronic changes in nearshore populations and communities.

Specific questions and objectives for each of the vital signs are:

Kelp and Seagrass

Question:

- What are the large-scale (GOA-wide, over decades) trends in the relative abundance and distribution of canopy forming kelps, intertidal algae, and eelgrass?
- What are annual trends in the abundance of canopy forming kelps, intertidal algae, and eelgrass?
- How do inter-annual changes in relative abundance of eelgrass differ among locations?

Objective:

- Estimate long-term trends in abundance and distribution of kelp and eelgrass at various locations.

Marine Intertidal Invertebrates

Questions:

- How are the composition and relative abundance of intertidal algae and invertebrates changing annually?
- How do inter-annual changes in relative abundance of intertidal algae invertebrates differ among locations?

Objectives:

- Monitor long-term trends in species composition and abundance of algal and invertebrate species at various locations.
- Document how the size distributions of limpets (*Lottia persona*), mussels (*Mytilus trossulus*), and clams are changing annually at various locations.

Marine Birds

Question:

- How is the species composition and abundance of birds (and especially those closely linked to the nearshore, such as harlequin ducks and Barrow's goldeneye) changing annually during summer and winter?
- How do inter-annual changes in the number of bird species present and the relative abundance of birds differ among locations?

Objective:

- Estimate long-term trends in the seasonal abundance of seabirds and seaducks at various locations.

Black Oystercatcher

Question:

- How are the relative density (pairs per linear kilometer of shoreline) of black oystercatcher nests and the nest site productivity (number of chicks or eggs per nest) changing annually?
- How is the composition of prey provisioned to black oystercatcher chicks changing over time?
- How do inter-annual changes in density of black oystercatchers and composition of prey provisioned to chicks differ among locations?

Objective:

- Estimate long-term trends in relative density and nest site productivity of black oystercatchers at various locations.
- Estimate long-term trends in black oystercatcher diet through collection of prey remains at various locations.

Sea Otter

Questions:

- How is abundance and spatial distribution of sea otters changing over time?
- How is age-specific survival of sea otters changing annually?
- How is the diet of sea otters changing annually?
- How do inter-annual changes in abundance, survival, and diet differ among areas?

Objectives:

- Estimate long-term trends in sea otter abundance and spatial distribution.

- Estimate and compare age-specific survival rates of sea otters among regions within the Gulf of Alaska.
- Estimate diet composition of sea otters at various locations.

<u>Marine Water Chemistry and Quality</u>

Questions:

- What is the daily, seasonal, and annual variation in intertidal water temperature and salinity and how are these changing over time?
- How is the concentration of contaminants in mussel tissue (an integrated index of contaminant concentrations in water) changing over time?
- How do inter-annual changes in water chemistry and contaminant levels differ among locations?

Objectives:

- Document daily, seasonal, and annual variability in temperature and salinity at various intertidal sampling sites.
- Monitor status and trends in the concentration of metals, PAHs (polycyclic aromatic hydrocarbons often associated with oil spill contamination), PCBs, pesticides, and metals in the tissues of mussels collected from various locations over time.

2.3 Sampling areas

The design focuses on examining each of these vital signs in the Katmai National Park and Preserve (KATM), Kenai Fjords National Park (KEFJ), Western Prince William Sound (PWS). Less frequent sampling of selected vital signs will be examined in Lake Clark National Park and Preserve (LACL), Eastern PWS (EPWS), and Northern PWS (NPWS) (Figure 2).

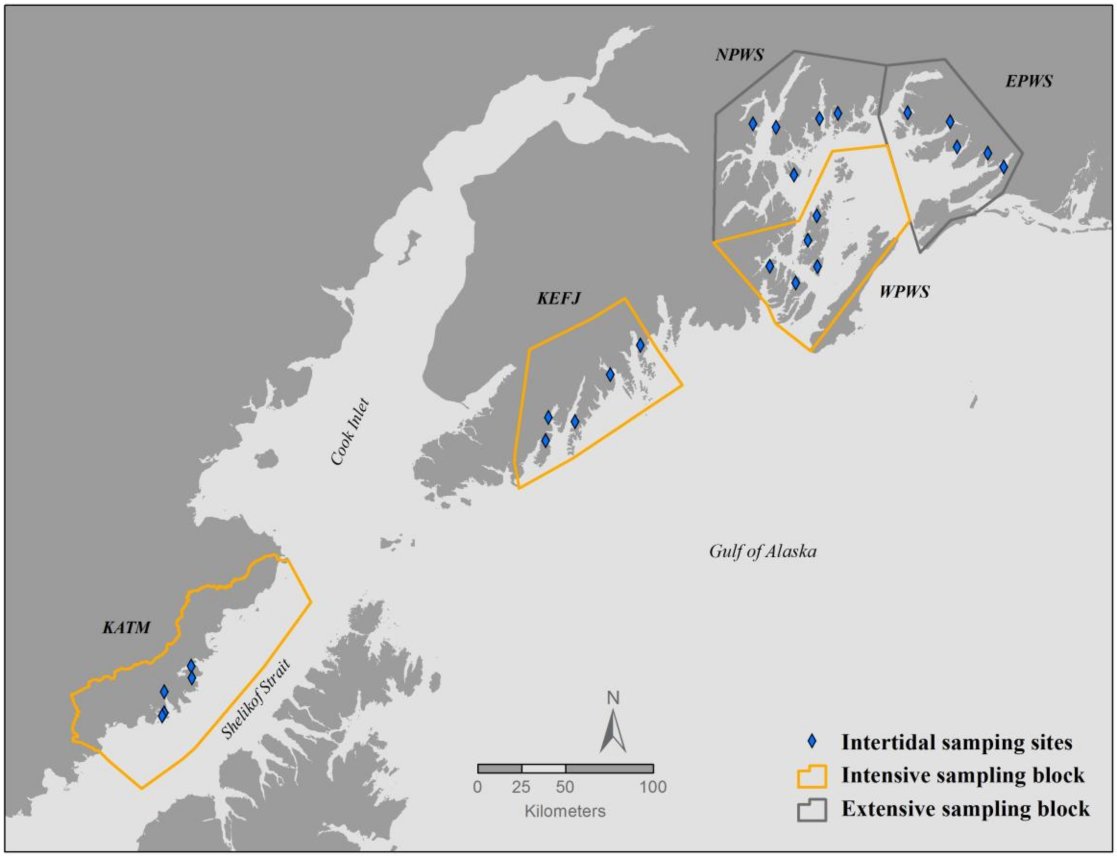

Figure 2. Areas for sampling within the Katmai National Park (KATM), Kenai Fjords National Park (KEFJ), and Western Prince William Sound (WPWS), Eastern Prince William Sound (EPWS) and Northern Prince William Sound (NPWS).

Various vital sign metrics are evaluated on an annual (or for some metrics less frequent) intervals within each location. Sampling frequency was determined based on the expected extent of inter-annual variation for a given metric as well as cost and logistical constraints. For example, the species distribution and abundance of intertidal invertebrates that are known to exhibit high inter-annual variation are to be sampled either annually or bi-annually whereas less variable contaminant levels in mussel tissue are to be monitored every 7 to 10 years.

The number and location of sampling units differ among metrics, but in general the design calls for sampling at multiple locations within each area. The number of sampling locations and the rationale for this are specified in vital sign specific SOPs, but in general were guided by preliminary estimates of effort required to detect ecologically meaningful levels of change. Sampling locations were selected to provide a random, spatially balanced distribution. The design allows for detection of large temporal or spatial-scale changes (e.g. changes that may occur over the entire region over time or among blocks). For some metrics (e.g. contaminants in mussels) the design will also allow for detection of changes that may occur on a more localized scale (e.g. at a site of heavy human influence).

2.4 Sampling method overview

Sampling in the core intensive sampling blocks (KATM, KEFJ, and WPWS) will consist of:

- Surveys of eelgrass and kelp canopy – The area covered by canopy forming kelps and eelgrass will be evaluated based on block-wide aerial surveys (Harper and Morris 2004) to be repeated on a ten to twelve year frequency. Changes in percent cover by eelgrass will also be evaluated in selected eelgrass beds on an annual basis. Selected sites will be areas of historical eelgrass cover (as documented by previous ShoreZone mapping conducted by Harper and Morris 2004) that are the nearest sites where intertidal and algal invertebrates are sampled. The boundaries of each bed will be located (either visually or using a fathometer and underwater camera) and positions recorded using a GPS.

- Sampling of intertidal plants and invertebrates on sheltered rocky shores - Sites on sheltered rocky shores will be selected and sampled annually to estimate the abundance and distribution of intertidal invertebrates and algae. Five to six sites will be sampled within each block. Metrics will include number of algal and invertebrate species, abundances of selected dominant taxa and size distributions of limpets.

- Sampling of infaunal invertebrates in gravel / mixed-sand gravel shores - Sampling of infaunal invertebrates will be conducted every other year at gravel/mixed sand-gravel sites in each block. Sampling will focus on bivalves that are relatively large, long-lived, and common (Lees and Driskell 2006). Metrics obtained will include abundances of selected clam species and size distributions of several dominant species. Sediment samples will be obtained from gravel / sand-gravel site for determination of grain size distribution (every 6 to 10 years).

- Sampling of Pacific blue mussels in mussel beds – The density and size distribution of mussels will be measured annually in 5 mussel beds in each w. The focus will be on larger mussels that are important prey for sea otters, sea ducks, and black oystercatchers. The selected beds will be the nearest beds to sheltered rocky intertidal sampling sites.

- Sampling marine bird and mammal abundance – Marine bird and mammal abundance will be estimated via boat annually in summer. Sampling in PWS will be done by under a separate contract to the US Fish and Wildlife Service (Irons et al. 2011). In addition, winter sampling will be conducted in KATM and KEFJ every two to three years. Counts will be made along shoreline transects using the methods of Irons et al. (2000). The focus will be on estimating the abundance of birds closely linked to the nearshore including harlequin ducks, Barrow’s goldeneyes, and black oystercatchers (Webster 1941, Goudie and Ankey1986, Andres 1998). Surveys will be conducted in summer and winter so that abundance estimates can be obtained for birds with different seasonal patterns (e.g. harlequin ducks that are more abundant in winter and black oystercatchers that are more abundant in summer).

- Sampling of black oystercatcher nest site density and oystercatcher chick provisioning - The number of black oystercatcher nest sites will be surveyed annually along shoreline transects. The number of eggs and/or chicks present will be counted as an index of nest productivity. The species composition and relative abundance of oystercatcher prey provided to chicks will be evaluated by sampling prey remains at oystercatcher nesting sites (Webster 1941, Andres 1998).

- Aerial surveys of sea otter abundance - Sea otter abundance will be estimated within each block in the summer of every second or third year using aerial survey methods described by Bodkin and Udevitz (1999). These methods have been used to conduct annual surveys to estimate the abundance of sea otters in Prince William Sound since 1993 (Bodkin et al. 2002), and on a less frequent basis elsewhere in the GOA. The metric obtained will be numbers of sea otters per block. Changes in the spatial distribution of sea otters will also be examined using boat based surveys in summer.

- Sampling of sea otter diets - The species composition and relative abundance of sea otter prey will be estimated annually using direct observation of sea otter feeding (Calkins 1978, Estes et al. 1981, Dean et. al 2002). These observations will provide an assessment of foraging efficiency (energy obtained per hour of feeding) as well as the composition of prey being consumed by sea otters. The latter will provide an indirect measure of the composition and relative abundance of representative intertidal and subtidal invertebrates that are difficult to sample directly.

- Coastline surveys for collection of sea otter carcasses - Specified beach segments will be walked annually for collection of sea otter skulls. The segments will be in areas where sea otter carcasses accumulate and will be based on preliminary surveys. A tooth will be extracted from each skull and sectioned to estimate the age of the sea otter (Bodkin et al. 1997). The data on the age distribution of dead sea otters will be used to evaluate changes in age-specific survival and to develop age-specific survival estimates based on an age-structured demographic model (Monson et al. 2000, Bodkin et al. 2002).

- Sampling of water/air temperature, salinity, and contaminants in mussels- Intertidal water/air temperature will be measured at each of the sheltered rocky intertidal sites. Temperature recording devices will be fixed at the 0.5 m tidal elevation in the intertidal zone and will record temperature every hour on a year round basis. Initially, salinity will be measured one to two sites in each intensive block. It is anticipated that more sites will be added if instruments prove reliable. The concentration of contaminants will be measured in mussels collected form rocky intertidal sites once every ten years.

In EPWS and NPWS, sampling will be limited to intertidal invertebrates and algae, eelgrass, mussels in mussel beds, infaunal invertebrates in gravel/mixed-sand gravel shores, water/air temperature, salinity, and contaminants in mussels. Sampling will be conducted as described above for intensive sampling areas but on a less frequent basis (every other year). Sampling within the LACL region will be limited to estimating abundance of infaunal invertebrates on gravel / mixed sand gravel beaches every 5 to 10 years. There is little rocky habitat within this region, and there are few sea otters or black oystercatchers.

A summary of the sampling design, with sampling sites and sampling frequency associated with each task, is given in Table 1.

Table 1. Summary of sampling design indicating sampling locations, number of sites sampled per location (if applicable) and frequency of sampling for each task.

Tasks	**Sampling sites**	**Frequency**
Kelp and eelgrass surveys	ShoreZone mapping over entire KATM, KEFJ, LACL, and PWS	1 per 12 to 15 years
	KATM, KEFJ, and WPWS -5 eelgrass beds per block	1 per year
	EPWS and NPWS - 5 eelgrass beds per block	1 per 2 years
Sheltered rocky intertidal invertebrates and algae	KATM, KEFJ, and WPWS – 5 sites per block	1 per year
	EPWS and NPWS - 5 sites per block	1 per 2 years
Limpet size distribution	KATM, KEFJ, and WPWS - 5 sites per block	1 per year
	NPWS and EPWS - 5 sites per block	1 per 2 years
Gravel / mixed sand gravel intertidal invertebrates	KATM, KEFJ, WPWS, NPWS, and EPWS - 5 sites per block	1 per 2 years
	LACL – 5 sites per block	1 per 5 to 10 years
Mussel size and density in mussel beds	KATM, KEFJ, and WPWS - 5 sites per block	1 per year
	EPWS and NPWS - 5 sites per block	1 per 2 years
Marine bird and mammal surveys - summer	KATM, KEFJ, and PWS[1]	1 per year
Marine bird and mammal surveys - winter	KATM and KEFJ	1 per 2 to 3 years
Black oystercatcher nest density and diet	KATM, KEFJ, WPWS - 5 sites per block	1 per year
Sea otter abundance (aerial surveys)	KATM, KEFJ, and WPWS	1 per 2 to 3 years
Sea otter diet	KATM, KEFJ, and WPWS	1 per year
Sea otter survival	KATM, KEFJ, and WPWS	1 per year

Tasks	Sampling sites	Frequency
Temperature	KATM, KEFJ, WPWS, EPWS, and NPWS – 5 sites per block	Year round
Salinity	KATM, KEFJ, WPWS, EPWS, and NPWS - 1 or more sites per block	Year round
Contaminants in mussels	KATM, KEFJ, WPWS, EPWS, and NPWS – 5 sites per block	1 per 5 to 10 years

[1]Bird surveys in PWS will be conducted by USFWS

Aerial digital video surveys of all shorelines (ShoreZone mapping) will be obtained approximately every 15 years using methods described by Harper and Morris (2004). The aerial video surveys are designed to characterize the geomorphology of shorelines within the region and to estimate large-scale spatial patterns of distribution and abundance for eelgrass, canopy forming kelps, and dominant benthic invertebrates and algae in the intertidal (e.g. brown algae and mussels). All of the shoreline within our study area has been surveyed in this manner over the past several years (Harper and Morris 2004). We also anticipate that satellite imagery describing sea–surface temperature and other physical chemical factors (e.g. surface chlorophyll) will be obtained and used as part of the nearshore program.

2.5 Design selection and alternatives considered

The GOA nearshore monitoring program described here grew from a lengthy developmental process involving extensive input and evaluation from the public, resource agencies, and the academic community. The initial program development for the National Park Service (Bennett et al. 2006) outlined the goals and objectives, identified vital signs, and outlined a process for future program development. In the same time frame, the *Exxon Valdez* Oil Spill Trustee Council sponsored a series of studies and workshops to develop a more geographically comprehensive program for monitoring changes in the nearshore over the region from Kodiak to Prince William Sound. The design presented here evolved from these earlier efforts that developed a conceptual design (Schoch et al. 2002), evaluated several design alternatives (Bodkin and Dean 2003), and provided a detailed nearshore monitoring and restoration plan (Dean and Bodkin 2006). The plan presented by Dean and Bodkin (2006) called for sampling within three blocks of approximately 10,000 km^2 within each of four regions: Kodiak archipelago, Alaska Peninsula, Kenai Peninsula, and Prince William Sound. A variety of metrics associated with the nearshore resources including sea otters, other marine mammals and birds, invertebrates, and algae were to be evaluated at various locations within each region. More frequent and comprehensive (in terms of metrics evaluated) sampling was to be conducted within one intensively sampled block per region. The sampling in intensive blocks was focused on detecting changes that may occur over larger spatial scales such as those associated with changes in climate. The plan also called for less frequent sampling at more widely dispersed sites within each of the 12 blocks that was aimed at detecting more localized changes such as those associated with point source discharges of contaminants.

A modified plan was initially implemented within KATM in 2006 and extended to KEFJ and LACL for the Southwest Alaska Network (SWAN) of the National Park Service as described in Dean and Bodkin (2011). The plan was based on the larger EVOS plan, but with several key differences. First, the SWAN nearshore vital signs program focused only on the three blocks that include KATM, KEFJ, and LACL. Second, only metrics that were identified as SWAN vital signs are to be measured. Finally, most of the emphasis was on intensive sampling within the KATM and KEFJ blocks aimed at evaluating large geographic-scale impacts. The plan was initiated on a limited basis in WPWS in 2007, and was fully implemented in WPWS, NPWS, and EPWS, starting in 2010 under funding from the Exxon Valdez Oil Spill Trustee Council (EVOS).

In the process of developing the SWAN and EVOS Nearshore monitoring programs we investigated most, if not all of the active nearshore monitoring programs along the west coast of North America (e.g. PISCO, MARINe, LIMPET, NAGISA, PSP, NOAA mussel watch). Where feasible we adopted and designed species and location specific procedures that would facilitate comparison of common metrics among existing and prior programs. For example, we employ point contact methods to estimate percent cover of intertidal invertebrates and algae that are similar to PISCO and MARINe methods and will facilitate comparison. We also estimate densities of large motile invertebrates (e.g. stars), that will be comparable to estimates from PISCO, MARINe, and other programs employing comparable techniques. In many instances species differences existed between existing nearshore monitoring programs in the contiguous US and Alaska requiring modification to available procedures. Where appropriate we adopted widely used and published methods to estimate marine bird densities (Irons et al. 2000) black oystercatcher abundance and diet (Andres 1998, Webster 1941) and sea otter abundance (Bodkin and Udevitz 1999), diet (Calkins 1978, Estes et al. 1981), and survival (Monson et al. 2000). There are however fundamental differences between some of the objectives of the GOA monitoring program described here and other nearshore monitoring programs. These include a GOA program objective to allow statistical inference to the entire region and therefore required a random component to site selection, rather than focusing on specific selected sites. Compared to other existing programs, GOA sites are remotely located and access is difficult and costly. As a result, our sampling frequency is generally equal to or greater than one year (with a few exceptions such as water quality), with limited ability to detect within year variation or trends. Furthermore, there are additional location-specific factors (e.g. a large tidal prism and high degree of disturbance due to ice and storms) that led us to different sampling designs than employed by other programs. Perhaps most importantly, the GOA program attempts to encompass all major elements of the nearshore trophic web: kelps and seagrasses as primary produces, benthic invertebrates as primary consumers, and the birds and mammals as apex predators (i.e. black oystercatchers, sea ducks and the sea otter). We know of no other nearshore monitoring program that incorporates this breadth of trophic interaction that will allow both “bottom-up” and “top-down” perspectives on causes of change in the nearshore marine ecosystem. This approach required adapting existing procedures where available and appropriate, and developing new ones as needed.

2.6 Selection of the sampling universe

As indicated above, sampling will be largely restricted to the KATM, KEFJ, PWS, and LACL coastlines, and will be concentrated in three blocks (KATM, KEFJ, and WPWS) (Figure 2). There are a wide variety of habitats within these regions. These are classified into ten predominant geomorphologic types (Ford et al. 1996): fine-medium sand beaches, coarse sand beaches, mixed sand-gravel beaches, gravel beaches, exposed rocky shores, exposed wave-cut platforms, sheltered rocky shore, exposed tidal flat, sheltered tidal flat, marsh. For the purpose of the GOA monitoring program, we intend to restrict sampling of intertidal invertebrates and algae to sheltered-rocky shores and to gravel and mixed sand-gravel beaches. We selected these habitats because they represent over half (about 58%) of the shorelines within the region (Ford et al 1996); are biologically diverse; harbor both hard bottom (epibenthic) and soft bottom (infaunal) organisms; are tractable to sample, and have a wealth of historical data relative to other habitats. Thus, they provide excellent indicators of change. Of the other habitats, exposed rocky shores or exposed wave-cut platforms are the most represented. However, these are generally less accessible for sampling. The habitats that we do not intend to sample are clearly of ecological importance (e.g. tidal flats as critical habitats for birds), but focusing sampling efforts on a few representative habitats should produce a monitoring plan that is more sensitive and more likely to detect change.

Also, with the exception of sampling of eelgrass and indirect examination of subtidal invertebrates via sampling of sea otter diets, we have largely excluded sampling in the subtidal. While the subtidal is an important part of the system, cost considerations prohibited us from examining this habitat more closely.

2.7 Selection of the size and number of sampling units

The size and number of sampling units to be included for evaluation of each metric within a given sampling period are given in Table 2 and described in detail in specific Standard Operating Procedures. A sampling unit is defined as the smallest unit for which a particular metric is measured and expressed. For example, the number of sea stars will be counted within a 200 m^2 area and expressed as number per 100 m^2. For each metric, the size of the sampling unit and number of sampling units varies dependent largely on the behavior of the species associated with the vital sign being examined. In estimating abundance of larger, more motile species that have large and variable home ranges that can cover large portions of a block (e.g. sea otters), sampling will be conducted along relatively large random or systematically placed transects of several hundred meters or more that cover the entire block. For species that do not move about or have limited home ranges (e.g. many invertebrates) sampling will be conducted at discrete, permanently established sites within each block. A site is here defined as an approximately 50 to 100-m section of coastline and the water directly adjacent to it. For these smaller, less motile species, sampling will be conducted within quadrats or transects ranging in size from approximately 0.10 to 200 m^2 at each site. The number of transects or quadrats sampled per site will range from one (for larger invertebrates like sea stars) to 24 (divided equally between two vertical strata) for smaller invertebrates and algae. The intent is to sample a number of units that will provide sufficient statistical power to detect changes ranging from 20% to 80% (dependent on the metric, see section 2.9 below). These criteria were selected as ones that were both biologically meaningful and achievable given budgetary and logistical constraints.

Table 2. Overview of the sampling designs used in the evaluation of each vital sign.

Vital Sign	**Primary metric**	**Sampling unit**	**Size of sampling unit**	**Number of sampling units per stratum & sampling period**	**Selection process for sample locations**	**Strata**	**Smallest spatial scale at which trends will be examined**
Kelp and seagrass	Proportion of shoreline with canopy forming kelps and eelgrass	Block	Entire block shoreline	None	Not applicable	Blocks	Block
	Eelgrass bed area	Transect	Variable, ~ 200 m long	5 sites per block	Closest to rocky intertidal site	Blocks	Site
Intertidal invertebrates and algae – rocky shores	Sea stars abundance	Transect	200 m^2	5	GRTS	Blocks	Site
	Intermediate invertebrate (*Nucella* spp. and *Katharina tunicata*) abundance	Quadrat	2.0 m^2	12 quadrats per transect,10 transects per block (5 at each of 2 tidal elevations)	GRTS for transect, systematic with random start for quadrats within transect	Mid and lower intertidal transects, blocks	Tidal level of transect at a site (50 m long)
Intertidal invertebrates and algae – rocky shores	Sessile invertebrate and algae abundance	Quadrat	0.25 m^2	12 quadrats per transect, 10 transects per block (5 at each of 2 tidal elevations)	GRTS for transect, systematic with random start for quadrats within transect	Mid and lower intertidal transects, blocks	Tidal level of transect at a site (50 m long)
	Limpet density and size distribution	Quadrat	Variable based on density of limpets	120 per site, pooled from 6 quadrats	GRTS for site, systematic with random start for collection sites	Blocks	Site
Intertidal invertebrates – gravel/sand	Intertidal invertebrate abundance	Quadrat	0.25 m^2	12 quadrats per transect, 5 transects per block	Closest to rocky intertidal site, systematic with random start for quadrats [1]	Blocks	Site

Table 2 (continued). Overview of the sampling designs used in the evaluation of each vital sign.

Vital Sign	Primary metric	Sampling unit	Size of sampling unit	Number of sampling units per stratum & sampling period	Selection process for sample locations	Strata	Smallest spatial scale at which trends will be examined
	Clam size, by species	Quadrat	0.25 m^2	Variable, dependent on the number of clams per site	Closest to rocky intertidal site, systematic with random start for quadrats. [1]	Blocks	Site
Mussels in mussel beds	Density	Quadrat	Variable based on density ($\leq$1m^2)	10 quadrats per site	Bed closest to rocky intertidal site, systematic with random start for quadrats.	Blocks	Site
	Size distribution	Quadrat	Variable based on density ($\leq$1m^2)	10 quadrats per site	Bed closest to rocky intertidal site, systematic with random start for quadrats.	Blocks	Site
Marine birds and mammals	Density	Transect	Variable, 2.5 - 5 km long x 200-m wide	30-40	Systematic with random start	Winter/summer, Blocks	Block
Black oystercatchers	Nest density	Transect	Variable, ~ 20-km long	5-6	Centered on GRTS site	Blocks	Block
	Productivity – eggs and chicks per nest site	Nest site	Variable	Variable, dependent on nest density	Selected, dependent on nests sites	Blocks	Block
	Diet – Relative abundance of prey	Nest site	Variable, ~ 100 m^2	Variable, dependent on nest density	Selected, dependent on nests sites	Blocks	Block
Sea otter	Abundance (aerial	Transect	Variable, ~ 0.4	Variable, ~200	Systematic with	Blocks	Block

Table 2 (continued). Overview of the sampling designs used in the evaluation of each vital sign.

Vital Sign	Primary metric	Sampling unit	Size of sampling unit	Number of sampling units per stratum & sampling period	Selection process for sample locations	Strata	Smallest spatial scale at which trends will be examined
	survey)		to > 10 km		random start		
Sea otter	Diet – Relative abundance of prey, energy obtained per hour	Feeding bout	Not applicable	Variable, ~50	Selected, dependent on where feeding otters are observed	Blocks	Block
	Age at death	Individual carcass	Not applicable	Variable, ~ 30	Selected, dependent on where dead otters are found	Blocks	Block
Water Quality - Contaminants, temperature, and salinity	Concentration of contaminants in mussels	Site	Not applicable	60 per site, pooled from 12 quadrats per site	GRTS for site, systematic with random start for quadrats used for collection within site	Blocks	Site
	Temperature	Recorded every 30 minutes year round	Not applicable	1 recorder per site, 48 observations per day	GRTS for site	Block	Site
	Salinity	Recorded every 30 minutes year round	Not applicable	1 recorder per site, 48 observations per day	One or more GRTS sites	Block	Site

[1]At LACL, sites were selected using the GRTS process since rocky sites were not sampled.

2.8 Locations for sampling

For ShoreZone surveys (Harper and Morris 2004) of kelp canopy cover and eelgrass cover, the entire shorelines of each block are censused. Eelgrass beds used to estimate change in abundance annually were selected as the eelgrass bed closest to sites used for sampling of intertidal invertebrates (see below).

Discrete sampling sites used to sample intertidal invertebrates and algae on sheltered rocky shorelines were selected using a generalized random tessellation stratified (GRTS) sampling scheme (Stevens and Olsen, 2004). This design provides a random yet spatially balanced distribution of sites within block. A GRTS design also allows for expansion or contraction of the number of sites to be sampled over time by pre-selecting a large number of sites that are ordered with respect to priority. Thus, sampling sites can be added or deleted without compromising the statistical or spatial integrity of the design.

Rocky intertidal sampling sites were selected using S-Draw, a windows-based GRTS sampling software program developed by McDonald (2005) (the users guide (GRTS for the Average Joe: A GRTS Sampler for Windows) for downloading the program go to: http://www.west-inc.com/computer.php). First, shorelines representing sheltered rocky or gravel/mixed sand gravel geomorphologic types were identified using Geographic Information System (GIS) software. The shoreline classifications used were from Environmentally Sensitive Index (ESI) maps produced for each region (RPI, 1983a, 1983b, 1985, 1986). The shorelines for a given habitat type were then divided into 1-m long segments and a data file was produced which contained all segments within each block and their geographic coordinates. The S-Draw software was then used to produce an ordered list of 100 potential sampling sites within each block. A "pixelsize" of 1 m was used in the selection process to maintain a relatively widely dispersed array of sampling sites. In cases where two sites were in close proximity to one another (two or more within an embayment of a size roughly equivalent to 1 km^2) we eliminated the second site within that bay and chose the next site in the ordered list for sampling. This was done to maintain a relatively even spatial distribution. The actual sites sampled were not specified until an "on site" evaluation of habitat type was made. It was well known that there were misclassifications in the ESI index maps (Sundberg et al 1996) and in some cases selected sites were not of the appropriate habitat or were inaccessible. In these cases sites were either moved to appropriate habitat up to two hundred meters from the selected location, or if there was no appropriate habitat within two hundred meters, alternative sites within the same bay were selected from the GRTS list of sites. The location of sampling sites is given in Figures 3a through 3d.

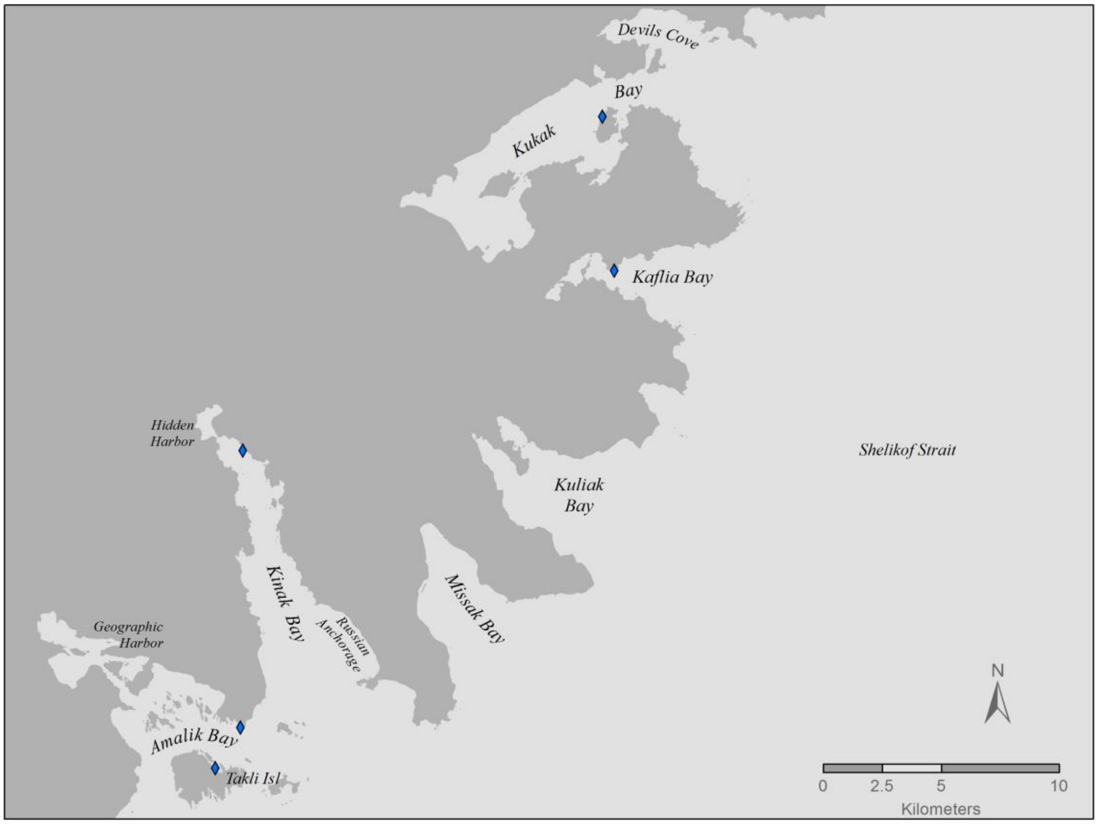

Figure 3a. Locations of intertidal invertebrate and algae sampling sites in Katmai National Park and Preserve.

Figure 3b. Locations of intertidal invertebrate and algae sampling sites in Kenai Fjords National Park.

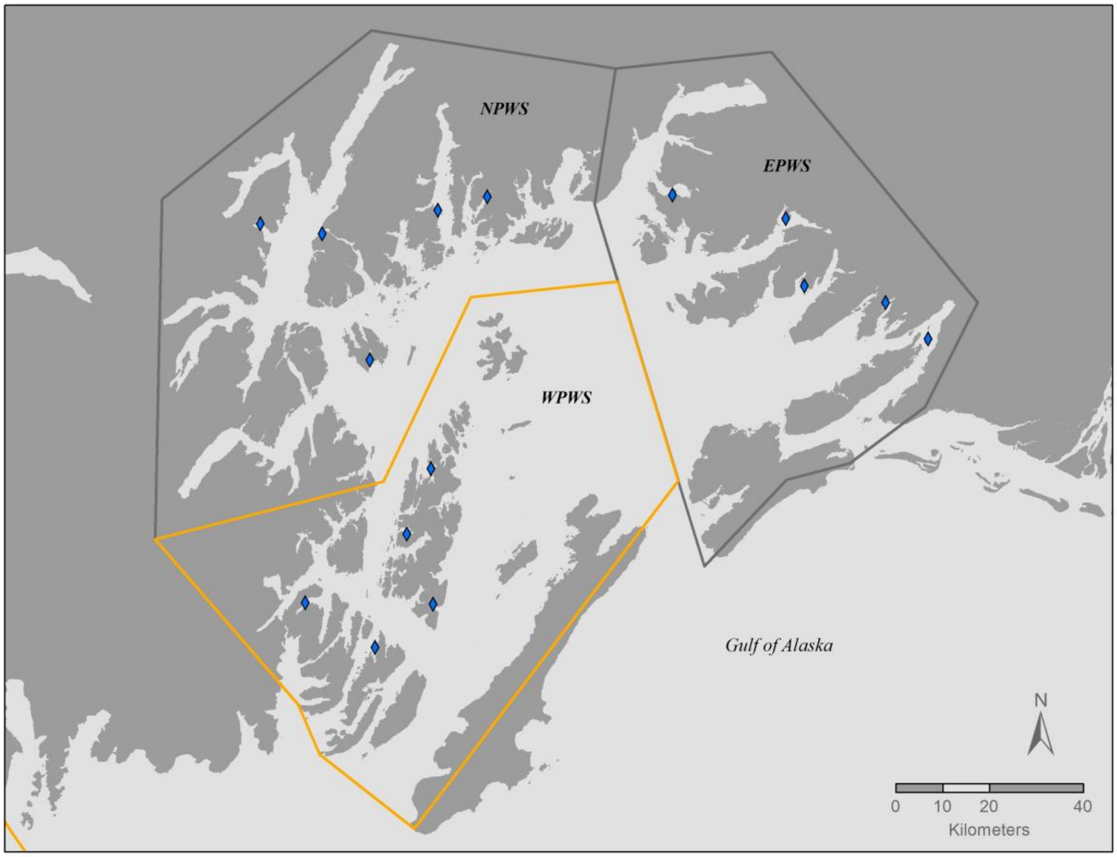

Figure 3c. Locations of intertidal invertebrate and algae sampling sites in Prince William Sound.

Figure 3d. Locations of intertidal invertebrate sampling sites in Lake Clark National Park and Preserve.

Transects for sampling clams and mussels were selected based on proximity to the GRTS rocky intertidal sampling sites. Clam and mussel sites were identified by appropriate habitats (unconsolidated sediments for clam and consolidated rocky for mussels) and the presence of clams and mussels. Transects used for sampling of marine birds and mammals were selected using a systematic selection with a random start point along the entire coastlines of each sampling block.

Transects used for estimating black oystercatcher density were centered on sites used to sample intertidal invertebrates on rocky shores. Nest productivity is to be estimated at each nest site located within these transects and prey composition is measured at any nest site where prey are observed.

Sea otter abundance (aerial surveys) is to be estimated using counts of sea otters along transects within defined sea otter habitat throughout each block that were selected systematically with a random start point. Sea otter foraging observations are to be made at sites wherever sea otters are seen foraging within a 5 km radius of invertebrate sampling sites. This radius roughly corresponds to the annual home range for sea otters. Sampling will be focused as close to the invertebrate sites as possible but will be dependent on the presence of sea otters required to obtain the minimum sample of 50 forage bouts per year. Carcasses of sea otter skulls are collected from wherever skulls are found within each block, but will focus on specific locations where large numbers of sea otter carcasses have been found in the past.

Black oystercatchers are to be sampled on transects centered on the selected rocky intertidal sites. Sampling of intertidal invertebrates on sand/gravel beaches, mussels in mussel beds, and eelgrass will be sampled at sites of appropriate habitat type that are closest to the randomly selected rocky intertidal sites. We chose to focus samplings for these metrics around the randomly selected rocky sites rather than an independent set of randomly selected sites because of the logistical constraints (a reduction in travel time between sites) and because of a desire to geographically link sites for sampling of all metrics as closely as possible while still maintaining a random component. Water quality metrics (contaminants in mussels, temperature, and salinity) are to be measured at sites identified for sampling of intertidal invertebrates on rocky shores.

Temperature and salinity are to be sampled at the rocky intertidal sites and contaminants will be measured in mussels collected from either rocky intertidal or nearby mussel sites.

In addition to sites selected using the GRTS design, sampling may also be conducted at several sites that are selected based on their proximity to locations of probable future impact from shoreline development, sites with historical data of interest, or sites of special interest to local citizens. These sites will be selected based on their proximity to specific resources of interest (e.g. sites particularly important as bird nesting and feeding habitats), based on their proximity to sources of potential anthropogenic disturbance (e.g. near boat harbors or population centers), or sites that have been sampled in the past and can be utilized to capture historical data and extend historical data sets. A list of some potential selected sites is given in Table 3.

Table 3. Potential selected sampling sites.

Selected sites	Block	Reason for Inclusion
Ninagiak Island	KATM	Bird nesting site and sea otter foraging site.
Illiamna Bay	AP	Port site (mining logging)
Sukoi Bay	AP	Close to shipping lane

Data obtained from randomly selected sites that were chosen using the spatially balanced GRTS procedure can be used to make inference to the specific habitat and block with respect to the parameters measured at these sites. Data from selected sites cannot be used in this manner, but will likely be beneficial in detecting localized change. Sampling sites that are anticipated to be of high risk to anthropogenic disturbance or have historical data should enhance our ability to detect change and likely will provide early indicators of change that might trigger further studies.

2.9 Sampling frequency

The frequency of sampling will vary with metric (Table 2). In general, biological metrics will not be sampled at a frequency of more than once per year. Some physical measurements such as temperature will be measured more frequently in order to capture episodic events that may be determinants of changes in biological systems. Yet other metrics that are not as variable over time (e.g. shoreline geomorphology) will be measured less frequently than once per year, perhaps with additional sampling triggered by specific events such as an earthquake. As part of the monitoring program, we also advocate hypothesis-driven process studies and more focused studies of events of particular importance (e.g. a large die off of a particular organism). We anticipate that funds for such studies may need to be obtained from agencies other than NPS or EVOS. We also anticipate that such studies will not be initiated until after the first 5 years or more of monitoring has been completed. This will allow identification of particularly compelling trends and development of hypotheses regarding causes for change, and will allow funding to be built to a sufficient level to support meaningful studies.

2.10 Power and the levels of detectable change

As indicated in Section 2.1 above, the objective of the sampling program is to assess how various metrics change over time and how those changes vary with respect to location and one another. The levels of change that we can expect to detect and the time and spatial scales over which they are to be detected vary with metric. The spatial scales over which trends will be examined range from a block (for large motile species like sea otters) to a site (for smaller, less motile species like mussels) (Table 2). In general, the goal for most biological metrics (e.g. abundance of sea otters, harlequin ducks, or dominant intertidal invertebrates like mussels) is to detect levels of change that are deemed to be of ecological importance (see section 4.2.6 for a discussion of determination of levels of change that are deemed ecologically important for each metric). In general, we intend to detect changes ranging from 20 to 80% (depending on the metric) at a given location (e.g. KATM or PWS). The ability to detect change can be expressed as power, the probability that a given level of change could be detected given the sampling design employed. Power analyses can also be used as a planning tool, to determine the sampling effort required to detect a given level of change with a prescribed power. As indicated in Section 5.0 below, it is anticipated that one of the primary methods used to detect change will conceptually take the form of mixed-model analyses (McCullouch et al. 2008) that examine, at a minimum, time (year) and location as the primary factors. The location factor consists of blocks (and in some cases sites nested within each block) with replicate samples within the block. Various mixed models would examine the extent of variation for a particular metric that could be attributed to location (e.g. block or sites within a block), time, and the interaction between these factors.

The power of a given design to detect a given level of change depends on the sample mean, sample size (n) and variances for a given metric. Variances of importance in determining power are among locations (to detect a time effect), among times (to detect a location effect), and in the relation between locations over time (to detect an interaction). Unfortunately, for most of the metrics of interest in the GOA program, data have not been collected over multiple years within each region. Therefore, variances needed to conduct the appropriate power analyses (those required to determine sample sizes required to detect reasonable levels of change for time, location, or time by location effects) are currently unavailable for most metrics.

It may be possible to make a reasonable approximation of power for each metric by estimating ranges of means and variances, based in part on data from elsewhere, and then performing simulations to estimate a range in levels of detectable change that might be expected. However, these have not been performed to date because such an effort is outside of the current scope of work. This is especially the case given the number of metrics that would need to be examined. Instead, it is suggested that the appropriate power analyses be performed as data are gathered (after five years, and at five year intervals thereafter) to determine the power to detect changes and to modify sampling designs as required. These changes might suggest reducing sampling effort to achieve greater efficiency or increasing sampling effort in order to achieve reasonable power to detect change.

It is reasonable to assume that the power to detect a given level of change will increase over time as the number of surveys increases. This again stresses the need for conducting periodic power analyses to suggest modifications to sampling designs over time and to ensure efficiency in the sampling.

The power to detect a given level of change also depends on biases associated with a particular sampling regime (Tyre et al, 2003, Earnst et al. 2005). For example, these might include biases introduced by using different observers in aerial surveys of sea otters or birds or those associated with the inability to detect all individuals present. When possible, we will account for these biases in our analyses. For example, we will use COMDYN software (Hines et al. 1999) or similar procedures to account for potential biases resulting from differences in detection probabilities where appropriate (Nichols et al. 1998, see section 4.2 below). However, for some of the metrics we will examine, we have no easy means of accounting for biases (including those related to detection probabilities) and no corrections will be made. Specific methods used to account of undetected species or individuals, or the rationale for why this was not done are given in individual standard operating procedures.

3 Field Methods

Field methods used in the GOA nearshore monitoring program are outlined in specific standard operating procedures. In most instances, we rely on specific methods that have been field tested and used previously to successfully provide data for each metric.

It is a certainty that there will be technological advances over the coming years that will make for more efficient or more precise estimation of given metrics. Thus, it is anticipated that methods described in standard operating procedures will need to be modified over time. It is recommended that when new techniques are adopted, that there be a period when both new and existing protocols are conducted simultaneously. This will ensure that any protocol specific biases will be revealed and that the integrity of long-term data sets will be maintained.

4 Data Management

4.1 Purpose

Effective archival and communication of information can only be achieved through the use of a data management plan that provides a means of documenting and storing data and transferring information among scientists and the public. A comprehensive data management plan is currently under development with the assistance of NPS, USGS and EVOS staffs. It is anticipated that the plan will be developed under guidelines set forth for the larger NPS vital signs program (Mortenson 2006). The following outlines elements to be included in the data management plan and provides steps for implementation of the plan. The specific goals of the data management plan are:

Ensure accuracy and maintain integrity of the data as gathered by investigators.

1. Provide for an efficient exchange of information among investigators of the larger Gulf Watch Alaska (GWA) and SWAN monitoring program investigators, and between these investigators and NPS, USGS and EVOS staffs.

2. Provide a mechanism by which data and reports can be archived.

3. Provide a framework by which analyses presented in reports can be traced to methods used to collect data and to the underlying data obtained during the initial data collection.

4. Provide a mechanism by which managers and the public can gain access to the information obtained.

There are several keys to the successful implementation of such a plan. First, the plan must be a written document. Second, there must be a management framework that clearly defines responsibilities for the plan's implementation. Third, all scientific investigators and their staffs must be trained to ensure that all data are obtained and transferred as specified by the plan.

Here we provide a framework by which a more complete plan can be produced and implemented as the project progresses. The complete plan will include the standard operating procedures, data sheets to be used in data collection, a complete description of all metrics included in the data, and an outline of the database structure. Standard operating procedures will include field data sheets and examples of raw data files. A final database structure and design is yet to be completed. Also, the details of procedures and mechanisms for information storage and transfer have not been fully developed.

The data management plan is intended to be a "living" document that will change as procedures are modified. While we have attempted to anticipate all of the possible permutations, there are almost always changes required. One seldom is able to anticipate all of the potential problems associated with field studies, and the subtleties of the data being gathered.

4.2 Data managers and information flow

The data manager for the program will be a staff member who is responsible for the overall design and maintenance of NPS vital signs and Gulf Watch Alaska databases. After collection and timely review, all data files will be submitted by investigators to the data manager for inclusion in the vital signs (NPS), USGS and Gulf Watch Alaska databases. It will also be the responsibility of the data manager to ensure that hardware and software are provided for the transfer and archiving of information, and for the development of transfer protocols. It will also be the responsibility of the data manager to maintain the central database, to maintain an updated index or metadata database, and provide a means of disseminating information in the database to the other investigators, and the public.

It will be the responsibility of each investigator to ensure that the data presented to the data manager is in an appropriate, pre-determined format, and is an accurate representation of the data as collected. The investigators will designate specific persons on her/his staff who have authority to submit data or request data from the data manager.

4.3 Written documentation

Written documentation will primarily be provided in the form of the monitoring protocol provided here, standard operating procedures, and reports. All procedures, including field operations, laboratory analyses, data management, data distribution, report production, and the archiving of files will be provided in SOPs. All SOPs will contain the author's name, the draft number, the effective date of the SOP, a brief statement of its purpose, and the specific training required to use the SOP. The format will follow that outlined by Oakley et al. (2003). SOPs are to be reviewed every year and updated as required. New SOPs are to be written as new procedures are adopted.

4.4 Training

Before an SOP can be used, all of those persons who will utilize the procedure must be trained. The level of training will be dependent on the procedure and will be at the discretion of the principal investigator in charge of that particular task. At a minimum, all users will be required to have read the SOP, and to have demonstrated their understanding of it. More elaborate training procedures involving hands on training and proficiency testing may be required in some instances and will be defined in individual SOPs.

4.5 File structure and databases

An outline for a suggested file structure for the nearshore data management program is given below. Files are to be organized under major file-folder headings and subfolder headings including the following:

Administrative

Protocols

Bibliography_Documents

Graphics

Photos: not site ID photos

Data_Sampling (data used for site/transect selection process

Data_Collection: Data is organized by the data collection method and year. Once the data has been deemed clean, a copy is made for the 540_Data_QAQC directory.

\SOP1_Coastline_Surveys (sea otter carcasses)

\SOP2_Sea_Otter_Forage

\SOP3_Mar_Bird_Mammal_Surveys

\SOP4_Inverts_Rocky_Shores

\SOP5_Sea_Otter_Aerial_Surveys

\SOP6_Inverts_Gravel_Sand_Beaches

\SOP7_Black_Oystercatcher

\SOP8_Mussels_Beds

Data_Analysis

Data_QAQC: validated & verified seasonal data. (Staging area prior to import into master datasets).

Data_Master: master datasets. Lookup tables as well as field data.

Data_Design: Staging area for developing database applications.

Samples_Collected: Sample tracking database for collection, storage, analysis….

Reports_and_Presentations:

\Field trip

\Annual

\Final

\Presentations

\Posters

Field or laboratory data that are initially recorded in 'hard copy' form and later transferred to electronic form should be maintained by individual investigators. Raw data files are access, excel or similar files that may be entered and edited hard copy field or laboratory data sheets. Analysis files are those used to manipulate or provide summaries of statistical analyses of the raw data. Metadata files describe the contents of each raw or analysis file. With the exception of hard copy raw data files, all files are to be in electronic format and are to be maintained by the data manager.

Analysis flow diagrams describe procedures used to obtain a particular result (figure, table, or descriptive result) given in a report. Any presentation of data in a report will be accompanied by an appendix that lists an analysis flow diagram that describes the steps taken in producing the table or figure. This flow chart will allow one to trace the summary presentation back to field or laboratory data sheets and allow for efficient data audits. The diagram will indicate all the names of any intermediate databases used in the production of the final table or figure, as well as the names of all analysis files.

Sampling locations are to be described using latitude and longitude (degrees, decimal degrees) and the NAD 83 datum.

4.6 Acronyms and abbreviations

The database management system will use the following standardized abbreviations and acronyms:

Vital Signs:

- KELP = Kelp & Eelgrass
- MAII = Marine Algae and Intertidal Invertebrates
- MBM = Marine Bird & Mammals (live)
- BLOY = Black Oystercatcher
- SEOT = Sea Otter
- MADE = Marine Debris
- MACA = Marine Carcasses
- MAWQ = Marine Water Quality

Location Codes:

- KATM = Katmai
- ANIA = Aniakchak
- KEFJ = Kenai Fjords
- LACL = Lake Clark
- WPWS = Western Prince William Sound

- EPWS = Eastern Prince William Sound
- NPWS = Northern Prince William Sound
- SWAN = Southwest AK Network
- GWA = Gulf Watch Alaska

Status Codes

- Raw = raw
- Draft = draft
- QAQC = ready for import into a final database, verified, validated
- Final = final product (image, illustration, analysis, etc)
- InProg = a step or steps up from Raw, but QAQC not completed yet (data files), basically a 'work in progress' for other file types.

Files and directories are to be named according to the following naming standards. File names will use date for versioning as YYYYMMDD. Names are to be kept as short as possible, using abbreviations or acronyms as indicated above where applicable. Spaces and unusual characters (e.g. % or &), or reserved words (e.g. DATE) are to be avoided in both folder and file names. Conventions for commonly used file types are as follows:

Reports

AuthorLastNameFirst Initial_YEAR_CODE_Title_YYYYMMDD.doc
(e.g. BodkinJ_2004_AK_Forage_Depths_SeaOtters_200401.doc)

SOP Files

SOPNum_VitalSign_Method_Title_YYYYMMDD.doc
(e.g. SOP01_SeaOtter_Forage_DataCollection_200603.doc)

Field Data Sheets

SOPNum_VitalSign_Num_Title_YYYYMMDD.doc
(e.g. SOP01_SeaOtter_Forage1_FieldDataSheet_200603.doc)

Spreadsheets, Analysis Files (SAS Programs, Sigmastat, etc), GIS Files, etc:

SOPNum_VitalSign_Num_Title_Status_YYYYMMDD.xxx
(e.g. SOP01_SeaOtter_Forage1_Block10_ForageData_RAW_20061025.doc)

Images (non-data):

Code_YYYY_Description_###.jpg
(e.g. KATM_2006_BrownBear_and_Cub_001.jpg)

4.8 Metadata

Metadata will be created per Executive Order 12906 (1994) requiring the creation of metadata for all data sets as well as allowing metadata to be available to the public. Metadata structure will follow the Biological Data Profile of the Content for Digital Geospatial Metadata or the Metadata Profile for Shoreline Data for FDGC CSDGM standards, depending on data type. FDGC CSDGM standards as well as the above mentioned profiles may be found at the following website: http://www.fgdc.gov/metadata/geospatial-metadata-standards. Metadata databases will be developed to facilitate access to information in raw files, intermediate databases, and analysis files. Separate metadata databases will be developed for geospatial data (GIS coverages) and for non-geospatial data. These will contain at least the minimum requirements described in the FDGC CSDGM standards which are: Identification information (contains data entry fields that ask for citations, spatial domain, keywords, access constraints and analytical tool use) and Metadata Reference Information (contains data entry fields that ask for metadata date, metadata contact, metadata standard name and metadata version). Geospatial and non-geospatial metadata will be created using ArcCatalog (ESRI), Metavist, or similar software. Creation of metadata will allow for efficient searching of data not only for the proposed project participants, but for ease of data distribution and collaboration across disciplines and reduce the possibility of duplication. Investigators will be responsible for updating metadata information sheets associated with each file and forwarding these to the data manager.

It is anticipated that the data will be housed and served in a web accessible form. A website for this purpose has yet to be developed, but it is anticipated that this website will serve the following functions.

1. Provide general project information to other scientists and the public. This would include contact numbers, project descriptions, biographies of key personnel, a schedule of events, descriptions of new and exciting findings, and access to reports.
2. Provide a web-based server that will house all of the nearshore data, documents, etc. and will provide a means of accessing the data by project personnel as well as non-project persons. It is anticipated that some files (e.g. raw data files or certain correspondence files) will be accessible only to investigators. Others will be publicly available.
3. Provide a means of accessing the data in a linked and searchable fashion. For example, provide a means of obtaining information relating to a specific location such as: data on mussel abundance at a particular site, maps of the site based on GIS coverages, and shoreline aerial video of the site. Other important aspects include providing linkages between a particular data set with an SOP under which the data were collected or linking numerical data with images.
4. Create and maintain records of edits to data files and archive older versions of files.
5. Create a "community forum" bulletin board where members of coastal communities can record observations of significance. These might include observations regarding particular events such as when and where the first herring spawn occurred in a given year, unusual weather, or unusual occurrences of dead animals in the nearshore.

5 Analysis of Monitoring Data

5.1 General guidelines

It is important in developing a monitoring plan to determine how the data generated might be analyzed to detect change and how results of these analyses might be interpreted. Specific types of analyses to be performed will vary with metric and are detailed in specific standard operating procedures. The following provides a generic discussion of types of analyses to be used. In large part, the discussion focuses on changes (primarily declines) in the density or other important demographic measures (e.g. survival or size structure) of species that are currently relatively abundant. However, our sampling designs (especially for intertidal algae, intertidal invertebrates, and marine birds) are inclusive of both rare and abundant species. Therefore, we should also be able to detect increases in rarer species that may occur over time.

5.2 Selection of primary metrics

The number of potential metrics to be used in the evaluation of vital signs is large and not all metrics provide the same degree of information with respect to insights as to trends in vital sign resources. For example, over 70 taxa of invertebrates and algae were identified in 2006 and 2007 surveys of sheltered rocky intertidal sites at KATM. However, the majority of these are relatively rare and indices of abundance for many are highly variable over time. As a result, indices of abundance for most of the taxa encountered are not suitable as vital sign indicators. Therefore, we have chosen to limit the number of primary metrics used to evaluate various vital sign resources on a routine basis. In general, we selected metrics that were deemed to be of ecological importance and that could provide reasonable power to detect trends over time. A preliminary list of these metrics is given in Table 4 and the rationale for their selection is given below. Other "secondary" metrics will be maintained in the databases and used on an ad hoc basis to evaluate change. For example, the sudden dominance by an intertidal invertebrate species in surveys of rocky shorelines or in the diet of sea otters might be deemed important and evaluated as an indicator of change in the future.

Table 4. Primary vital sign metrics to be analyzed to detect changes in the nearshore system on a routine basis. Also given are preliminary guidelines for degree of change deemed ecologically important (as discussed below).

Vital sign	**Metric**	**Degree of change deemed ecologically important**
Kelps and seagrass	Km of coastline with canopy forming kelp (based on ShoreZone surveys)	50% reduction
	Km of coastline with eelgrass (based on ShoreZone surveys)	25% reduction
	Area with eelgrass present	25% reduction
Intertidal communities-rocky	Number of algal and invertebrate species	30% change
	Percent cover bare substrate	80% change
	Percent cover barnacles	80% change
	Percent cover *Fucus distichus*	80% change
	Percent cover *Alaria* sp.	80% change
	Percent cover *Neorhodomela/Odonthalia* spp.	80% change
	Density of *Nucella* spp.	80% change
	Density of *Katharina tunicata*	80% change
	Density of sea stars	80% change
	Density of *Evasterias troschelii*	80% change
	Size distribution of *Lottia persona*	50% change
Intertidal community- soft	Density of *(Leukoma staminea)*	80% change
	Density of *Saxidomus gigantea*	80% change
	Density of *Macoma* spp.	80% change
	Size distribution of *(Leukoma staminea)*	50% change in mean size
	Size distribution of *Saxidomus gigantea.*	50% change in mean size
	Size distribution of *Macoma* spp.	50% change in mean size
Intertidal Community – mussel beds	Density of *Mytilus trossulus* >20 mm	80% change
	Total biomass of *Mytilus trossulus* >20 mm mussels	50% change
Marine birds	Number of bird species - summer (including rates of local extinction, colonization, and turnover)	50% reduction

Table 4 (continued). Primary vital sign metrics to be analyzed to detect changes in the nearshore system on a routine basis. Also given are preliminary guidelines for degree of change deemed ecologically important (as discussed below).

Vital sign	**Metric**	**Degree of change deemed ecologically important**
	Number of bird species – winter (including rates of local extinction, colonization, and turnover)	50% reduction
	Abundance of harlequin ducks in winter	50% reduction
	Abundance of Barrow's goldeneye in winter	50% reduction
	Abundance of black-legged kittiwakes in summer	50% reduction
	Abundance of glaucous-winged gulls in summer	50% reduction
	Abundance of pigeon guillemots in summer	50% reduction
	Abundance of cormorants in summer	50% reduction
	Abundance of scoters in summer	50% reduction
	Abundance of harlequin ducks in summer	50% reduction
Black oyster catcher	Density of active nest sites	50% reduction
	Number of chicks or eggs per nest site	50% reduction
	Species composition of prey remains (proportion of *Mytilus trossulus* , *Lottia persona, Lottia scutum,* and *Lottia* spp.)	Not determined
	Size distribution of remains of dominant prey (*Mytilus trossulus* and *Lottia persona*)	Not determined
Sea otter	Abundance (number per region based on aerial surveys)	40% change
	Proportion of dominant prey in diet (proportion of clams, mussels, crabs, and "other")	35% change
	Hours required to obtain energy required for maintenance.	20% increase; 33% decrease
	Proportion of carcasses in young, prime age, and aged age classes	40% change in any class
Water quality	Mean yearly air temperature, water temperature, and salinity	None
	Average daily range in air temperature, water temperature, and salinity	None
	Minimum and maximum air temperature, water temperature, and salinity	None
	Concentration of PAHs, PCBs, DDTs, Chlordanes, Total HCH (organopesticides), and	Concentrations that exceed the mean of all sites sampled in the U.S.

Table 4. Primary vital sign metrics to be analyzed to detect changes in the nearshore system on a routine basis. Also given are preliminary guidelines for degree of change deemed ecologically important (as discussed below).

Vital sign	**Metric**	**Degree of change deemed ecologically important**
	selected heavy metals in mussel tissue.	mussel watch program (see Table 5 below).

Kelp and seagrasses – Monitoring of kelp and seagrass (eelgrass) requires estimation of changes on several different spatial scales. We will examine larger temporal- and spatial- scale changes in the distribution of canopy forming kelps and eelgrass by examining the changes in the km of shoreline occupied by kelps and eelgrass based on ShoreZone mapping surveys (Morris and Harper 2004) conducted approximately every 15 years. For eelgrass, we will estimate the area covered by eelgrass and categorical estimates of eelgrass density in selected eelgrass beds annually.

Intertidal community - Algae and Invertebrates on sheltered rocky shorelines – For intertidal invertebrates and algae, we will examine number of species present and rates of local extinction, colonization, and turnover based on the presence or absence of species (Nichols et al. 1998) using COMDYN software (Hines et al. 1999). We will also examine changes in abundance of selected species. Species selection was based on surveys conducted at 5 sites in KATM in 2007 and 2008 (Bodkin et al 2007, 2008), at KEFJ in 2008 (Bodkin et al. unpublished data), and at PWS in 1989-1991 (Highsmith et al. 1994). In these surveys, over 70 taxa of invertebrates and algae were identified, but most were rare and offer little power to detect changes in their abundance over time. As a result, we choose to limit the number of metrics we will examine as vital sign indicators to the percent cover of bare substrate (indicating the absence of sessile invertebrates and algae), the total number of sessile and small motile species encountered, the total number of sea stars species, and the percent cover or number per unit area of several relatively abundant and ecologically important taxa. Indices of abundance (either based on percent cover or density) will be evaluated for five taxa of sessile invertebrates and algae: barnacles, *Mytilus trossulus*, *Fucus distichus* susp. *evanescens*, *Alaria* sp., and *Neorhodomela/Odonthalia* spp. These taxa are widely distributed, dominate the intertidal in terms of percent cover (together contributing over 90% of cover), and are important as the primary structural and energetic components in the rocky intertidal community. For larger motile invertebrates, we will evaluate the abundance of 4 sea star species (*Evasterias troschelii*, *Pisaster ochraceus, Pycnopodia helianthoides*, and *Dermasterias imbricata*), the large chiton *Katharina tunicata*, and the predatory snail *Nucella* spp. *Katharina* is an important grazer in this community (O'Clair and O'Clair 1998) and sea stars and *Nucella* spp. are important keystone predators (O'Clair and Rice 1985, O'Clair and Zimmerman 1987, Carroll and Highsmith 1996, O'Clair et al. 1999). We will also examine size distributions of *Lottia persona* that are abundant and are important prey for higher trophic levels (especially black oystercatchers) (O'Clair and O'Clair 1998).

Intertidal community - Invertebrates on sand-gravel beaches - For intertidal invertebrates on sand/gravel beaches, we will examine changes in abundance and size distribution of selected species. Species selection was based on surveys conducted in KATM and KEFJ (Lees and Driskell 2006, Coletti et al. 2009) that focused on the abundance, size distribution, and diversity of clams. A total of over 25 species were found, most of which were rare (fewer than 10 individuals in 12 – 0.25 sq. m. quadrats per site) and offer little power to detect change in their abundance over time. As a result, we choose to initially limit the number of metrics we will examine as vital sign indicators to the density and size distribution of three dominant taxa (*Leukoma staminea*, *Saxidomus gigantea,* and *Macoma* spp.). The three taxa selected for consideration are also important prey for sea otters (Calkins 1978, Estes et al. 1981, Kvitek et al 1992, Dean et al. 2002). While we will focus on these more abundant species at present, all larger bivalves are counted and measured and could be included in future analyses should their abundance increase over time.

Intertidal community- mussel beds – We define mussel beds as sites with relatively high densities of Pacific blue mussels, *Mytilus trossulus*. Specifically, mussel beds are defined as areas with greater than 10% cover by mussels within contiguous 1 m^2 quadrats over areas of 100 m^2 or greater. Metrics used to evaluate changes in mussel beds will include the average density of large mussels (greater than 20 mm in length), and the mean biomass of mussels greater than 20 mm in length (the minimum size generally taken by black oystercatchers and sea otters). Biomass will be estimated based on density and size distribution data gathered at each site, and on previously established relationships between size and biomass (O'Clair et al. 1999).

Marine birds – Evaluation of marine birds rely primarily on summer and winter boat based surveys that provide indices of density for each species encountered. We will examine the number of species present and rates of local extinction, colonization, and turnover based on the presence or absence of species in each season (Nichols et al. 1998). We will also examine changes in estimates of abundance of selected species chosen based on their relative abundance and ecological importance in the nearshore. In summer surveys conducted in KATM and KEFJ in 2006 and 2007, more than 30 species of birds were identified and counted. Most of these were rare. While we may include these species in our analyses should they become more abundant over time, we will focus only on relevant species that currently provide more statistical power to detect changes in abundance over time. The taxa selected for evaluation include three that nest in the nearshore and feed primarily on schooling fishes (black-legged kittiwakes, glaucous-winged gulls, and pigeon guillemots) and five that are more reliant on nearshore benthic food resources (harlequin ducks, goldeneye, mergansers, cormorants, and scoters). We elected to examine genera instead of species for some birds (goldeneyes, mergansers, cormorants, and scoters) because of occasional difficulty in distinguishing between closely related species within these genera during field surveys. Previous boat-based surveys in Prince William Sound (Irons et al 2000) found that abundance estimates for all of these taxa provided reasonable power to detect changes (greater than 50% power to detect a 50% reduction or a doubling in abundance between oiled and unoiled areas based on a sample size of 123 transects).

Black oystercatchers – Oystercatcher density will be estimated in marine bird surveys (see above) and in specific summer boat-based surveys. We will also estimate nest site density and will use this as a primary vital sign metric. In addition, we will evaluate nest site productivity as estimated based on the average number of eggs or chicks per nest, and will evaluate the composition of remains of prey brought to nest sites. Metrics to be evaluated for prey composition will include the proportion of the predominant prey items (primarily mussels, chitons and several limpet species) as well as the size distributions of predominant prey.

Sea otters – We will examine changes in number of sea otters (based on aerial survey estimates) as a primary metric of interest in evaluating changes in sea otter populations. However, sea otters are relatively long-lived marine mammals (generally reaching 15 years of age or greater) with relatively low birth rates and changes in abundance may not be the most sensitive indicator of long-term trends in abundance. Nor will changes in abundance offer any clues as to the causes for change. As a result, we will also evaluate trends in age-specific mortality rate (as indicated by the proportion of carcasses in each of three age classes: 0 to 3, 4 to 8, and >8 years of age). In addition we will evaluate changes in diet over time. Metrics to be evaluated will include the proportion of predominant prey items in sea otter diets (proportion of mussels, clams, crabs, and other prey). We will also estimate the total prey energy obtained per hour of feeding by sea otters. The latter is used to estimate food availability (Dean et al. 2002) and incorporates data on the composition and sizes of prey as well as dive times and intervals between dives.

Marine Water Chemistry and Water Quality – Water quality will be evaluated by measuring temperature and salinity in the intertidal zone and the concentration of various metal and organic contaminants in the tissue of mussels. For temperature and salinity, we will evaluate changes in yearly mean, mean daily range,, and minimum and maximum yearly values. We will focus on ranges and extreme values because these are often important disturbance events that can regulate community structure of intertidal algal and invertebrate communities (e.g. Carroll and Highsmith 1996). A total of over 120 organic compounds or isomers and ten metals are measured in the tissue of mussels. For organics, we will evaluate several summary metrics including total PAHs, total chlordanes, total DDTs, total PCBs, and total HCHs) as indicators of exposure to contaminants in the nearshore.

5.3 Routine annual analyses

Annual reports will include primarily descriptive analyses that present means and confidence intervals for each primary metric over various spatial scales. The plots of means over time will be made to examine trends over the spatial scales of the region (means for KATM, KEFJ, and WPWS), within a block (e.g. KATM) and in the case of metrics in which multiple sites are examined, for sites within a block (Figure 4).

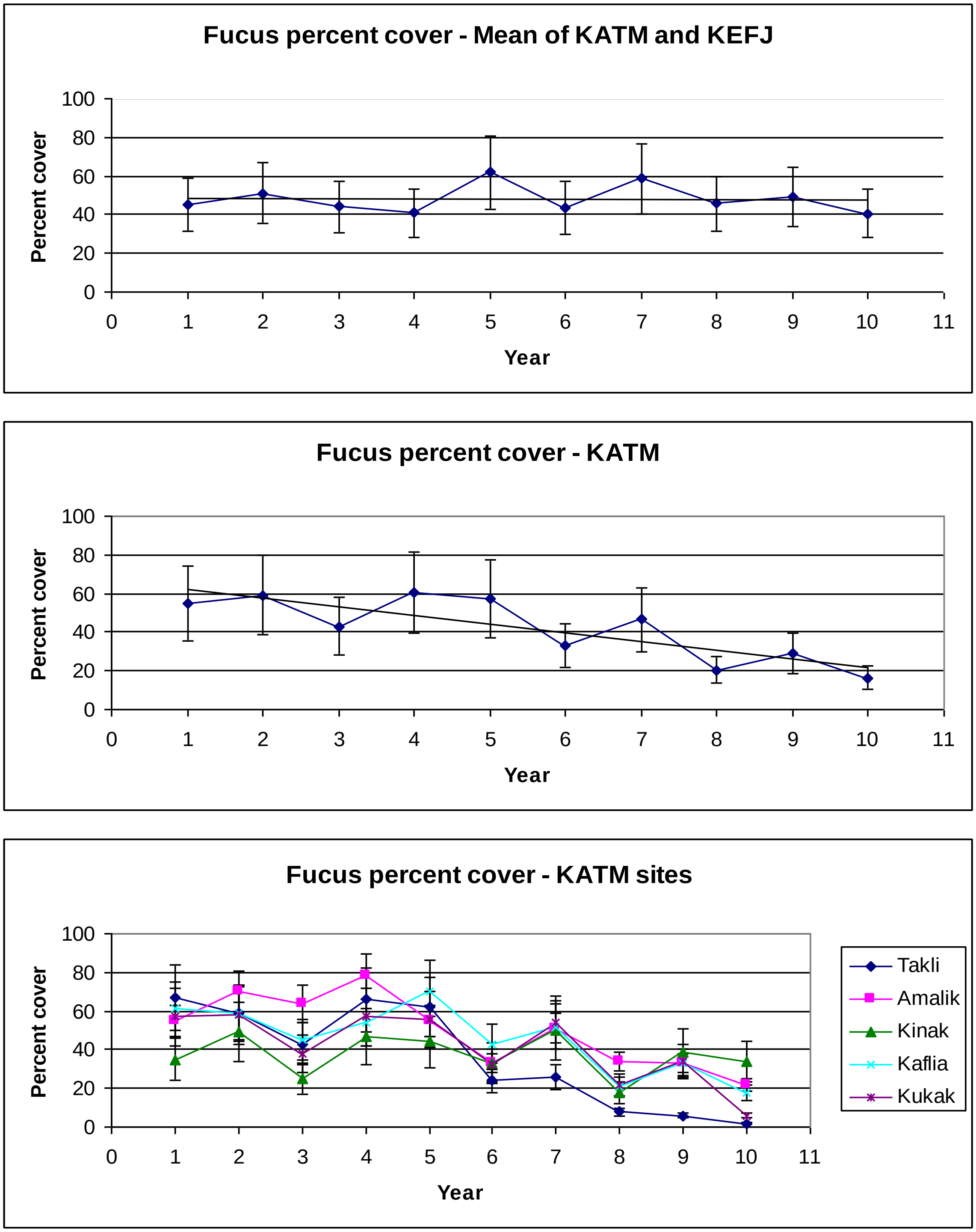

Figure 4. Example plot of mean and confidence intervals over time for hypothetical data for percent cover of Fucus for regions, blocks (e.g. KATM), and sites within blocks..

5.4 Analyses to detect trends

Analyses to detect trends in the data will be conducted after five years of data have been collected for a given metric and at 2 to 5 year intervals thereafter. The specific analyses performed will depend in part on the metric and on any patterns or observed trends. The following provides a general discussion of types of analyses that are being considered.

Different types of analyses may be required if trends are gradual and occur at a relatively consistent rate over time or are episodic (e.g. extreme shifts in a given year based on an extreme event such as an earthquake or particularly hard freeze). Trends that result from extreme events will be modeled using either change-point or segmented regression (Seber and Wild 1989, Küchenoff and Carol 1997). More gradual changes will be examined using linear or log-linear regression models.

The general approach to be used in trend analysis is as follows. Several hypotheses (models) will be selected a priori that might provide reasonable explanations of trends in the observed data, and we will use information-theoretic (I-T) criteria to rank these models based on their relative support and select the best-fitting model to generate our trend estimate (Burnham and Anderson 2002, 2004; Lukas et al. 2007). If more than one model is reasonably supported, we will use model averaging to generate our estimates (Burnham and Anderson 2002). In the simplest form, models used to examine trends in various vital signs (e.g. sea otter abundance) will include explanatory variables of time (e.g. survey year), location (e.g. block), and the interaction of time and location. (This would result in the simultaneous testing of 6 models with parameters of year; location; year and location; year and the interaction of year and location; location and the interaction of year and location; and year, location, and the interaction of year and location.) Where appropriate, models examined will include terms that might account for potential biases in the data, such as the years of observer experience or observer identity for a given sea otter aerial survey. Terms that might further explain trends over time (e.g. mean annual temperature, location relative to a particular local disturbance, or time period relative to a particular disturbance event) may also be included where appropriate. Terms such as observer identity that are likely to lack independence in influencing dependent variables in successive years be will be treated as random effects. The regression analyses are to be performed using the Proc Mixed function in SAS (SAS 2000) or comparable software.

5.5 Analyses to provide insights as to causes

Causes for observed environmental changes can only be determined by use of specific experimental designs. However, we can gain some insights as to possible causes for change using two primary analytical methods. First, the spatial and temporal patterns of change, and the scales over which they occur, will be examined using the analytical tools described above. The temporal and spatial scales of change should help to suggest possible causes. For example, a change that occurs over decades and is roughly of equal magnitude at all locations (a time effect of ecological importance, but no location or time by location effect) would suggest that the change was due to some large-scale event (e.g. global climate change or PDO), rather than a more localized one (e.g. a release of a toxicant from boat harbors). Second, inclusion of explanatory variables in models might also suggest cause. For example, if inclusion of the concentration of contaminants in mussels helps to provide a better fit of temporal trends in black oyster catcher abundance, then this might suggest that a decline in oyster catchers was related to an increase in contaminants.

It should be stressed that we will not be able to definitively assign causes for changes based solely on the data generated in this monitoring plan. Assigning cause will rely heavily on further process studies that are designed to test hypotheses regarding specific cause and effect relationships. These process studies cannot be designed or carried out until there is sufficient observational or correlative evidence produced to detect a change and suggest a possible cause.

5.6 Ecological thresholds and management trigger points

The objective of the GOA nearshore monitoring program is to examine trends in various metrics that are indicative of changes in the health of the nearshore community. However, the ultimate goal of the program is to provide resource managers with the tools that will allow them to take actions to protect resources. Therefore, in addition to identifying trends, it is also necessary to provide some guidance as to what levels of change are ecologically important and to identify "trigger points" that warrant consideration of action on the part of managers (Nichols and Williams 2006).

Determining when a trend is ecologically important is not a straightforward process. There is currently no standard by which to measure ecological importance, and there are no clear guidelines to determine "trigger points" for action by resource managers. Various models have been proposed to evaluate threats to threatened or endangered species (e.g. IUCN 2002), but these are generally not appropriate for our use. Few of the species we are monitoring as vital signs are in danger of extinction, and our hope is that we can identify trends of ecological importance and inform managers so that actions can be taken to protect resources prior to reaching the status of threatened or endangered. Furthermore, the geographic scale of concern is different. For example, it is possible to have declines in abundance of a particular species that is of concern to resource managers, but relatively insignificant to the continued survival of the species. There is currently a NPS funded study to help identify a process that may help to determine these trigger points based on structured decision making and on models of system behavior (Nichols et al. 2007). Our intent here is to provide some interim guidance for ecologically important trends for each metric we are considering. We stress that these are preliminary. While such values are needed to guide analyses and interpretation of results, there is little precedent for establishing ecological thresholds. It is anticipated that these will be modified over time based on further empirical and theoretical analyses.

Our preliminary guidance on possible trigger points is based largely on our understanding of the species within the nearshore system of the GOA and interactions between these species. In general, we deem important changes that are likely to have system-wide effects through predator –prey interactions, for example. This is based largely on our conceptual understanding of the system and not on a more rigorous systems model. Where possible, we will rely on two types of data to help identify trends of ecological importance. The first is the range in natural variation that has been observed in what are considered healthy populations. These variations represent the bounds to be placed on any reasonable trigger point. The second is the range in variation, generally expressed as a level of change that has been considered ecologically important in past studies of impacts to nearshore ecosystems, and especially those that have been shown to have larger system-wide effects. We will rely heavily on observations made following the *Exxon Valdez* oil spill, since the spill is widely recognized as having significant long-term impacts on the nearshore ecosystem. The spill affected nearshore communities in KATM, KEFJ, and more strikingly in PWS, was widely studied over a period of several decades. In some cases, there is an absence of data on levels of natural variation in healthy systems or examples of the levels of change that have proved to be of ecological importance. In these cases we make use of our best professional judgment to estimate levels of natural variation and levels of change that may be of ecological importance.

It is unlikely that we will ultimately rely solely on any single metric to evaluate the health of the nearshore system. Instead, we will likely rely on change in a suite of metrics viewed in the context of a community or systems model. For example, reductions in intertidal mussel populations coupled with a reduction in mussels as a component of the diet in sea otters and black oyster catchers would provide stronger evidence of an important ecological change than would reductions in mussels alone. However, it is important to provide trigger points for each metric as an initial step in this process.

The guidance provided is given in terms of absolute levels of change from current conditions. However, in some instances it may be appropriate to also examine trends in the relative levels of change at one location compared to others. Tracking relative change may be important in identifying locations that are changing in response to a site specific disturbance event, especially in cases where there are larger geographic-scale temporal changes that are occurring in response to normally occurring climatologic or oceanographic change. For example, relatively small absolute declines in abundance at a given location might be deemed important if abundances elsewhere are increasing, and relative changes at that given location are large in relation to other locations. We assume that the magnitude of relative change that is ecologically important is the same as the level of absolute change. For the sake of simplicity, we discuss only absolute changes below. However, it should be recognized that relative levels of change may be of interest and will be similarly evaluated.

The actions that might be undertaken by mangers when a trigger is exceeded cannot be determined and will be resource and event dependent. Actions might range from continued or more detailed study to more specific conservation measures such as limiting of visitation to sites where declines are observed or removing potential sources of contamination. It is likely that future consideration of possible management decisions will be made based on a weight of evidence provided.

Preliminary guidance on changes deemed to be of ecological importance for each vital sign metric is as follows:

Kelps and seagrasses – The natural variation in the cover of canopy forming kelps in the Gulf of Alaska is largely unknown. However, kelp canopies in the GOA and elsewhere are known to fluctuate in response to oceanographic conditions (e.g. storm activity, water temperature, light, and nutrient availability), grazing, competition, and human disturbance (North 1964, Neushul 1981, Dayton 1985, Foster and Schiel 1985). Therefore, we will recognize only relatively large (greater than 50%) reductions in canopy cover within a block (based on aerial ShoreZone mapping) to be of ecological importance.

Dramatic changes in the abundance of eelgrass have been observed over the past several hundred years (Costa 1988, Short and Wylie-Echeveria 1996). Changes are generally associated with disease and human disturbance. While some eelgrass beds along exposed coastlines are subject to high inter-annual variability due to storms, those in more sheltered habitats (like most in KATM, KEFJ, and PWS) display relatively little variation from year to year (Costa 1988, Short and Wylie-Echeveria 1996, Ward et al. 1997). Longer-term (5 to 10 yr.) declines in beds of 25% or more, in these types of sheltered habitats are generally attributable to human disturbance and are considered to be of ecological importance. We have few data on the trends in abundance of eelgrass at KATM, KEFJ, or PWS, but based on the relative lack of annual variation made in sheltered eelgrass beds elsewhere in Alaska (Ward et al 1997), we consider reductions of 25% or greater in the km of coastline occupied by eelgrass, or in the area covered by eelgrass at selected eelgrass beds, to be of ecological importance.

<u>Algae and invertebrates on sheltered rocky shorelines -</u>Inter-annual patterns of abundance of intertidal invertebrates and algae on rocky shores are highly variable. Most of the species have high mortality rates due to intense grazing or predation and because of their susceptibility to natural disturbances including wave action, freezing, and desiccation. In what are regarded as healthy systems in the Gulf of Alaska, it is not unusual to see inter-annual changes in estimates of percent or abundance of dominant intertidal invertebrates and algae that are 50% or greater (Highsmtih et al 1994, Skalski et al. 2001). At sites impacted by the *Exxon Valdez* oil spill, only larger changes (on the order of 80 to 90%) were deemed to be of ecological importance. Based on these results, we consider changes in abundance of selected dominant taxa of 80% or greater be of ecological importance. Changes in the number of species present are somewhat less variable, and inter-annual variation in the number of species detected is generally less than 20%. Impacts from the *Exxon Valdez* oil spill caused changes in number of species of algae detected that were on the order of 30% or greater. We consider changes of 30% or greater ecologically important. Based on 3 years of data from KATM, size distributions of limpets, *Lottia persona*, appear to vary relatively little over time. Median sizes at any one site varied less than 20% over the three year period. We have no data on longer-term changes in limpet size, but suspect that changes in median size on the order of 50% or greater may be ecologically important.

<u>Invertebrates on sand-gravel beaches</u> – In the Gulf of Alaska, there are relatively few data regarding the normal range of variability in clam assemblages on sand-gravel beaches or on levels of change that are ecologically important. Additionally, the sampling methods are by necessity destructive and preclude sampling at high frequency. As a result variation in mean density values within clam beds over time are generally high. Within clam beds sampled in multiple years in Glacier Bay, mean densities of dominant species varied by as little as 10% and as much as 300% (J. Bodkin, unpublished data). Similarly, Houghton et al. (1996) found relatively high inter-annual variability in clam densities in PWS (at sites unaffected by the Exxon Valdez oil spill). Because of the lack of data from many of our sampling sites (especially KATM and KEFJ) and the anticipated high spatial and temporal variance, we will use values for clam densities of 80% to represent changes that are deemed ecologically important. Reductions on the order of 80% or greater were observed at sites that were washed after the Exxon Valdez spill and were deemed ecologically important (Houghton et al. 1996). We also lack size data for dominant intertidal clams from KATM or KEFJ, but

expect variation in mean sizes to vary much less than density. As a consequence we expect a 50% change in mean size of dominant intertidal clams to be ecologically important.

Intertidal community- mussel beds – Little is known about the persistence of beds of Pacific blue mussels (*Mytilus trossulus*) or changes in density, sizes, or biomass of mussels within beds over time. A two-year study in Price William Sound indicated that year to year variations in density and biomass were as high as 50%. Longer-term studies of two closely related species, California mussels (*Mytilus californianus*) and blue mussels (*Mytilus edulis*) suggest that mussel beds can persist for decades but that the boundaries of the bed and changes in biomass of mussels within a bed can change appreciably. Studies indicate that while beds can persist for a decade or more, occasional episodic large disturbance events (storms associated with El Nino events or ice scour associated with extremely cold winters) can cause local extinctions of some beds (Paine et al 1985, Seed and Suchanek 1992, Petraitis and Dudgeon 2004). Without specific information on the persistence and inter-annual variation in beds of Pacific blue mussels, it is difficult to set meaningful boundaries on changes that might be considered ecologically important. Until more data are provided we consider block-wide (e.g. within KATM, KEFJ, or WPWS) changes of 80% or greater in the average density and 50% change in the biomass of mussels to be ecologically important.

Marine birds –After the Exxon Valdez oil spill, Irons et al. (2000) found significant reductions in several bird species that were on the order of 50% or higher and were deemed of ecological importance. We will consider similar reductions (on the order of 50% or greater) as ecologically important. However, for many species of birds, inter annual variation is quite high, and it is likely that we only be able to detect somewhat higher reductions. For example, in Glacier Bay National Park, inter-annual variation for commonly observed species varied between 15 and 60%, (Drew et al. 2008) and even somewhat higher inter-annual variation was observed at KATM between 2006 and 2008 (Coletti et al. 2009).

Black oystercatchers - Black oystercatchers are long-lived, have high nest site fidelity and appear to have relatively stable nest site densities and productivity over time in the absence of major disturbance events (Andres 1997, Coletti et al. 2009). Following the Exxon Valdez oil spill in Prince William Sound, comparisons of changes in black oystercatcher density and productivity at oiled and unoiled areas after the spill implied that there was greater than 60% reduction in active nest density in areas impacted by the spill and an 80% reduction in nest productivity in areas disturbed by cleanup operations. Both were considered of ecological importance. Here we consider reductions in nest density or productivity that are 50% or greater to be of ecological importance. Changes in diet, including both changes in prey frequency and sizes of select prey within the black oystercatcher chick provisioning diet, are metrics we are using to assess black oystercatcher status. There are no prior studies to suggest what specific levels of changes in diet might be of ecological importance. In surveys conducted in KATM between 2006 and 2008 there were large changes in the diets of black oystercatchers over time (a 71% and 47% reduction in the proportion of *Lottia persona* and *Mytilus trossulus* respectively and a greater than 200% increase in the proportion of both *Lottia scutum* and *Lottia pelta*). However, there were no appreciable changes in either nest density or productivity of black oystercatchers over this period (Coletti et al 2009) and no obvious changes in the intertidal community at large. Therefore it is unclear as to the magnitude of change in prey size would be considered ecologically important. Thus, we will continue to monitor both prey composition and prey size to help us understand possible changes in community dynamics, but we cannot establish ecological thresholds for these metrics at present.

Sea otters – Estimates of abundance of sea otters based on aerial surveys are somewhat imprecise and in general 95% confidence intervals around the estimated population size in any given year are on the order of 20-30% of the mean. As a result of this imprecision and natural variation, population estimates for what are considered “healthy” sea otter populations that are relatively stable can vary by as much as 30% from one year the next. However, longer-term changes on the order of 40% or larger are thought to represent changes of ecological importance. Following the *Exxon Valdez* oil spill, reductions in the sea otter population in western Prince William Sound were on the order of 50% and were clearly considered to be of ecological importance. We will use a reduction of 40% or larger in sea otter abundance as our level of change considered as ecologically important. Also following the *Exxon Valdez* oil spill, increases of 60% in the proportion of prime age sea otters found beach-cast (17 to 28%) with corresponding decreases in the proportions of juvenile and aged adults (44 to 42%, and 40 to 31%, respectively) were considered biologically significant, contributing to a protracted period of recovery from the spill (Monson et al. 2000). Because these proportions are not independent, we will use a change of 40% in any of the three age groups as biologically significant, assuming a minimum total sample size of 100 ages at death. Sea otter diet appears relatively consistent over long time scales at some locations. For example the proportion of clams in the diet of sea otters in Prince William Sound in the 1970’s was similar to the 1990’s (about 70-80%, Calkins 1978, Bodkin et al. 2002). We will consider changes in dominant prey (those contributing 35% or more to the diet) of 35% or more to be biologically significant and indicative of change in the prey base. The estimated number of hours that sea otters must spend feeding in order to obtain sufficient energy for maintenance is generally on the order of 9-10 hours per day in stable and healthy populations. Increases in feeding time required for maintenance that excede 11 hours (20%) or decreases to less than 8 hours (33%) are considered to be of ecological importance.

Water quality: Temperature and salinity – Variations in temperature and salinity are potentially important drivers of ecological change. Therefore, we will measure and analyze temperature and salinity on a routine basis. Variations in temperature, and especially in temperature extremes, are known to vary greatly from year to year. Less is known regarding variations in salinity, but these too are expected to vary considerably in the nearshore zone that is highly influenced by the degree of freshwater runoff. However, longer-term variations in both temperature and salinity in the nearshore (and especially the intertidal zone) are largely unknown, as are the levels of change that are of ecological importance. Furthermore, no managerial action is anticipated even if ecological meaningful changes in these metrics are observed. Therefore, we set no thresholds for these metrics.

Water quality: Contaminants –Levels of contaminants in mussel tissue have been widely studied as an indicator of water quality. These data are used to indicate relative “hot spots” where concentrations of given contaminants are of potential concern. Relationships between concentrations of contaminants and adverse biological responses are less clear and no “threshold concentrations” indicative of adverse biological effects have been established. Therefore, we provide estimates of concentrations that are of ecological importance based on comparisons to those found elsewhere in the US. Specifically, we consider concentrations to be of ecological importance when mean for a given site exceeds mean values of all sites sampled in the US as part of the NOAA mussel watch program (O'Connor et al. 1996). We have chosen to use the mean rather than "high" values (those equivalent to one standard deviation above the mean based on log-transformed data) because the majority of sites sampled in the mussel watch program are from highly industrialized sites that are generally considered ecologically degraded relative to those in our sampling universe. Both means and "high" values for each contaminant are given in Table 5.

Table 5. Mean concentration and “High” values (those that exceed one standard deviation of the mean for log-transformed data) of contaminants in oyster and mussel tissue samples taken from sites (generally in industrialized urban areas) throughout the United States between 1986 and 1993. For silver, copper, zinc, lead and chromium values are for mussel tissue only. All others are for oysters and mussels. Data are from O’Connor et al. (1996).

Chemical	**Mean**	**“High”**
Metals (concentrations in µg/g)		
Arsenic	10	17
Cadmium	2.7	5.7
Mercury	0.094	0.24
Nickel	1.7	3.3
Selenium	2.5	3.5
Silver	0.17	0.58
Copper	8.9	11
Zinc	130	190
Lead	1.8	4.3
Chromium	1.7	3.0
Organics (concentrations in ng/g)		
tPCB	110	470
tDDT	37	120
tCdane	14	31
tPAH	260	890

5.7 Interpretation of results

For the biological metrics, we consider changes to be of ecological importance if a trend is established and if the trend is such that the threshold of ecological importance has been exceeded. Trends will be deemed to be established if the 90% confidence intervals about the time coefficient in trend analysis models do not include zero. Whether that trend is of ecological importance will be determined by examining the confidence intervals in relation to the threshold levels established (Alderson 2004) (Figure 5). For example, for sea otter abundance, we deem a 40% reduction of the population estimate to be a threshold. If the mean percentage change in the population estimate (as determined by the adjusted time coefficient in trend analysis over any given time interval) is less than 40% and the lower confidence interval about that mean does not include 40%, then no effect of ecological importance would be indicated. If the confidence intervals about the mean (either upper or lower) include a 40% reduction, then the results would be considered inconclusive. If the mean decline is greater than 40% and the upper confidence interval does not exceed the 40% level, then an ecologically important decline in the sea otter population would be indicated.

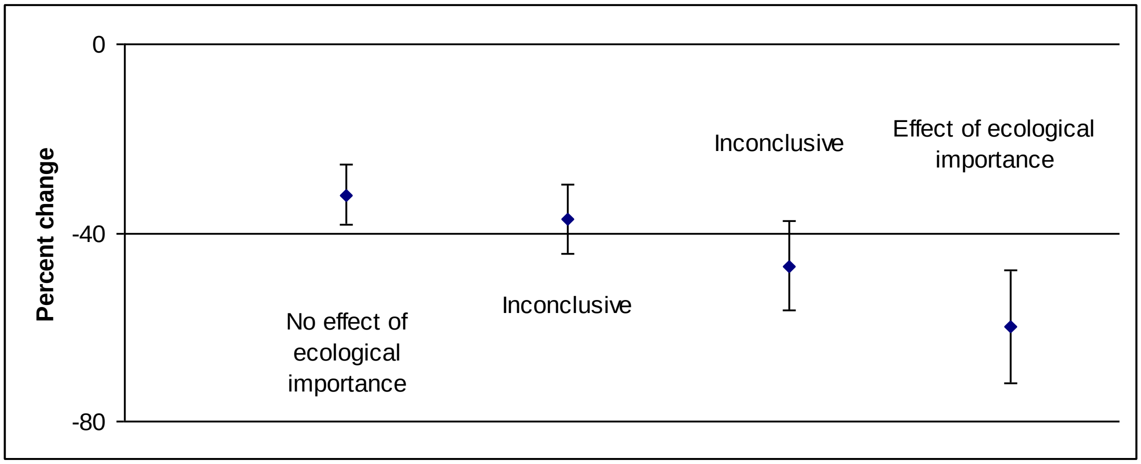

Figure 5. Interpretation of thresholds for consideration of action given means percentage change observed and 90% confidence intervals about those means. The horizontal line of no effect (-40%) is the threshold level of change deemed ecologically important.

6 Reporting

Three different levels of reporting are to be conducted. The first are annual reports that describe the activities for the previous year, summarize results in the form of annually updated figures and tables, highlight any unusual events or trends in the data, and describe activities to be conducted in the upcoming year. More comprehensive reports will be produced every five years that provide complete statistical analyses of data gathered to date, conduct power analyses as appropriate to examine possible changes to sampling designs, suggest changes to sampling designs, and suggest possible topics for process studies needed to examine causes for change or evaluate new sampling techniques. Also, it is anticipated that there will be special reports produced on an as needed basis that address patterns of observed change that require some immediate action such as increased sampling effort, initiation of process studies, or possible regulatory intervention. Special reports might also summarize the results for a particular time specific task such as evaluation of a potential modeling effort or a synthesis of results.

7 Management Structure, Personnel Requirements, and Training

7.1 Management structure and key personnel

This project is one of several conducted as part of the SWAN and Gulf Watch Alaska monitoring programs (Bennett et al. 2006, *www.aoos.org/**gulfwatchalaska***). The nearshore program described here will be jointly managed by leads from NPS and USGS. Data management functions will be directed by the NPS Data Manager. Other staff will be provided by NPS, USGS, NOAA, and private contractors.

7.2 Personnel requirements

The list of required staff (including contractors) and a brief description of their responsibilities and qualifications are given in Table 6.

7.3 Training

The level of training required for each of the project personnel will depend in part on their level of experience. At a minimum, training will consist of familiarization and demonstrated proficiency in safety procedures, data management procedures, and in implementation of standard operating procedures as required by the position. Required proficiencies for each task are outlined in standard operating procedures.

7.4 Schedule of activities

The following table (Table 7) summarizes the annual schedule for activities to be conducted in nearshore vital signs program.

Table 6. Anticipated staffing requirements and salary estimates for the GOA nearshore monitoring program. All salary estimates are given in 2013 dollars and include benefit and overhead costs.

Position and number required	Responsibilities	FTEs Required	Approximate Annual Salary
Lead Scientists (USGS and NPS)	Oversee project staff, budgets, scheduling, contracts, analysis, preparation of reports, and coordination with other contractors	1.6	$180,000
Lead Analyst	Oversee analysis of data. Assist in planning, field efforts, and report preparation	0.7	$90,000
Senior Scientists	Oversee field sampling. Assist in organization of data, maintenance of data bases, and report preparation.	0.8	$85,000
Biologists	Assist in preparation for field sampling, field sampling, data base maintenance, and data analysis	0.7	$80,000
Biologists - Technical support	Assist in field logistics, field sampling, data entry, and data base maintenance	1.1	$90,000
Data manager	Provide data management support, build and maintain data bases	0.2	$20,000
Seasonal field support technicians	Assist in field sampling	0.1	$10,000
Total		5.2	$ 555,000

Table 7. Summary of tasks completed through 2012 (in black) and tasks planned for 2013 and 2014 (in red) as part of the GOA nearshore monitoring program.

Metric	Area	2006	2007	2008	2009	2010	2011	2012	2013	2014
Eelgrass percent cover in	KATM			x	x	x		x	x	x
selected beds	KEFJ			x	x	x	x	x	x	x
	WPWS			x	x	x	x	x	x	x
	EPWS							x		x
	NPWS								x	
Invertebrate and algal	KATM	x	x	x	x	x		x	x	x

Table 7 (continued). Summary of tasks completed through 2012 (in black) and tasks planned for 2013 and 2014 (in red) as part of the GOA nearshore monitoring program.

Metric	Area	2006	2007	2008	2009	2010	2011	2012	2013	2014
abundance and limpet size	KEFJ			x	x	x	x	x	x	x
	WPWS		x			x	x	x	x	x
	EPWS							x		x
	NPWS								x	
Intertidal invertebrate	KATM		x		x		x		x	
abundance and clam size	KEFJ		x		x		x		x	
	WPWS		x				x		x	
	LACL				x					
	EPWS							x		x
	NPWS								x	
Mussel abundance	KATM			x	x	x		x	x	x
and size	KEFJ			x	x	x	x	x	x	x
	WPWS					x	x	x	x	x
	EPWS							x		x
	NPWS								x	
Bird density	KATM	x	x	x	x	x		x	x	x
- summer	KEFJ		x	x	x	x	x	x	x	x
Bird density	KATM				x			x		
- winter	KEFJ			x		x			x	
Black oyster catcher nest	KATM	x	x	x	x	x		x	x	x
density	KEFJ		x	x	x	x	x	x	x	x
	WPWS		x			x	x	x	x	x
Black oyster catcher	KATM	x	x	x	x	x		x	x	x
- prey relative	KEFJ		x	x	x	x	x	x	x	x

Table 7 (continued). Summary of tasks completed through 2012 (in black) and tasks planned for 2013 and 2014 (in red) as part of the GOA nearshore monitoring program.

Metric	Area	2006	2007	2008	2009	2010	2011	2012	2013	2014
abundance										
	WPWS					x	x	x	x	x
Sea otter abundance –	KATM			x				x		
aerial survey	KEFJ		x			x			x	
	WPWS	x	x	x	x	x		x	x	x
Sea otter diet – Prey	KATM	x	x	x	x	x		x	x	x
relative abundance	KEFJ		x	x	x	x	x	x	x	x
	WPWS					x	x	x	x	x
Sea otter age at death	KATM	x	x	x	x	x		x	x	x
	KEFJ		x	x	x	x	x	x	x	x
	WPWS	x	x	x	x	x	x	x	x	x
Contaminants in mussels	KATM			x					x	
	KEFJ			x					x	
	WPWS							x		
	EPWS							x		
	NPWS								x	
Temperature	KATM	x	x	x	x	x	x	x	x	x
	KEFJ			x	x	x	x	x	x	x
	WPWS					x	x	x	x	x
	EPWS							x	x	x
	NPWS							x	x	x
Salinity	KATM		x	x	x	x	x	x	x	x
	KEFJ		x	x	x	x	x	x	x	x
	WPWS					x	x	x	x	x
	EPWS							x	x	x
	NPWS							x	x	x

8 Operational Requirements and Cost Estimates

8.1 Operational requirements

Operational requirements for specific tasks are outlined in standard operating procedures. More generic operational requirements are given here.

Facilities and Office Equipment

- Office facilities for 6 staff
- Computers for above staff
- Central server for data storage and website (specifications and location to be determined)
- Software for data management, statistical analysis, geographic information system, and office management

Field Equipment

- 3 Inflatable vessels and associated power and safety equipment
- 16 to 24 ft vessel and associated power, electronic, and safety equipment
- 5 High power scopes for sea otter foraging observations
- 5 Ruggedized laptop computers for entry of field data
- 40 Temperature recording devices
- 6 GPS units
- 4 Digital cameras
- 6 Binoculars
- 10 salinity recording devices
- 2 Down-looking sonar recorders

Charter Vessels and Aircraft

- Minimum 50 ft vessel for charter with accommodations for 6 scientific staff
- Aircraft for aerial surveys for of sea otters
- Helicopter for access to the LACL sites

It is anticipated that many of the field equipment needs could be met using existing equipment, thereby eliminating the need for large initial capital expenditures.

8.2 Cost estimates

Cost estimates for the monitoring program are summarized in Tables 8. The cost estimates include in kind support from USGS and NPS for salaries and vessel charters. Not included is in kind support for facilities and existing equipment.

Table 8. Estimated annual budget for the GOA nearshore monitoring program. All costs are in 2013 dollars. Future costs require inflation adjustment.

Category	Annual cost estimate	Comments
Salary	$555,000	Detailed in Table 6. Includes salaries for USGS, NPS, NOAA, and contract personnel.
Vessel charter	$120,000	Includes costs for 4 summer and 1 winter cruise
Equipment purchase	$7,000	Computers, vessels, and field instruments
Travel	$8,000	Travel to meetings and to field
Commodities	$10,000	Includes fuel, software, field supplies
Contracts	$29,000	Includes contracts for aircraft and for chemical analysis
Agency overhead	34,000	
Total	$763,000	

9 Literature Cited

Alderson, P. 2004. Absence of evidence is not evidence of absence. BMJ 2004:476-477.

Andres, B.A. 1997. The Exxon Valdez oil spill disrupted the breeding of black oystercatchers. Journal of Wildlife Management 61: 1322-1328.

Andres, B.A. 1998. Shoreline habitat use of black oystercatchers breeding in Prince William Sound, Alaska. Journal of Field Ornithology 69(4): 626-634.

Andres, B., and M. DeZeeuw. 1991. Feeding ecology and reproductive success of black oystercatchers in Prince William Sound. *in* Restoration Project Report. U. S. Fish and Wildlife Service, Anchorage AK Restoration Project Report. U. S. Fish and Wildlife Service, Anchorage AK.

Barry J.P., Baxter C.H., Sagarin R.D., and Gilman S.E. 1995. Climate-related, long-term faunal changes in a California rocky intertidal community. Science 267:672-675.

Baxter R.E. 1971. Earthquake effects on clams of Prince William Sound. In: The great Alaska earthquake of 1964. Report to National Academy of Sciences, Washington, DC. Pp.238-245.

Bennett, A.J., W.L. Thompson, and D.C. Mortenson. 2006. Vital signs monitoring plan, Southwest Alaska Network. National Park Service, Anchorage, AK.

Bodkin J.L. and M.S. Udevitz. 1999. An aerial survey method to estimate sea otter abundance. p 13-26 *In*: G.W. Garner, S.C. Amstrup, J.L. Laake, B.F.J. Manly, L.L.McDonald, and D.G. Robertson (eds). Marine Mammal Survey and Assessment Methods. Balkema Press, The Netherlands,

Bodkin, J.L. and T.A. Dean. 2003. Monitoring in the nearshore: A process for making reasoned decisions. *Exxon Valdez* Restoration Project 030687. Final Report. Exxon Valdez Oil Spill Trustee Council. Anchorage, AK.

Bodkin, J.L., J.A. Ames, R.J. Jameson, A.M. Johnson, and G.M. Matson. 1997. Estimating age of sea otters with cementum layers in the first premolar. Journal of Wildlife Management. 61:967-973.

Bodkin, J.L., B.E. Ballachey, T.A. Dean, A.K. Fukuyama, S.C. Jewett, L. McDonald, D.H. Monson, C.E. O'Clair, and G.R. VanBlaricom. 2002. Sea Otter Population Status and the Process of Recovery from the 1989 *Exxon Valdez* Oil Spill. Mar. Ecol. Prog. Ser. 241:237-253.

Bodkin, J.L., T.A. Dean, and H.A. Coletti. 2007. Nearshore Marine Monitoring in the Southwest Alaska Network of National Parks. National Park Service. Anchorage, AK. 102 pg.

Bodkin, J.L., T.A. Dean, H.A. Coletti, and K.A. Kloecker. 2008. Nearshore Marine Monitoring in the Southwest Alaska Network of National Parks. National Park Service. Anchorage, AK. 179 pg.

Bodkin, J.L., B.E. Ballachey, and G.G. Esslinger. 2011. Trends in sea otter population abundance in western Prince William Sound, Alaska: Progress toward recovery following the 1989 Exxon Valdez oil spill: U.S. Geological Survey Scientific Investigations Report 2011-5213 14 pg.

Burnham, K.P. and D.R. Anderson. 2002. Model selection and multimodel inference. 2nd Ed. Springer-Verlag, New York.

Burnham, K.P. and D.R. Anderson. 2004. Multimodel inference: understanding AIC and BIC in model selection. Sociological Methods in Research 33:261-304.

Calkins, D.G. 1978. Feeding behavior and major prey species of the sea otter, *Enhydra lutris*, in Montague Strait, Prince William Sound, Alaska. Fishery Bulletin 76:125-131.

Carroll, M.L. and R.C. Highsmith. 1996. Role of catastrophic disturbance in mediating Nucella-Mytilus interactions in the Alaskan rocky intertidal. Mar. Ecol. Prog. Ser. 138:125-133.

Coletti, H., J. Bodkin, T. Dean, and K. Kloecker. 2009. Nearshore marine vital signs monitoring in the Southwest Alaska Network of National Parks. Natural Resource Technical Report NPS/SWAN/NRTR—2009/155. National Park Service, Fort Collins, Colorado.

Connell, J.H. 1972. Community interactions on marine rocky intertidal shores. Annual Review of Ecology and Systematics 3:169-92.

Connolly, S. R., B. A. Menge, and J. Roughgarden. 2001. A latitudinal gradient in recruitment of intertidal invertebrates in the northeast Pacific Ocean. Ecology 82(7): 1799-1813.

Connolly, S. R., and J. Roughgarden. 1999. Theory of marine communities: Competition, predation, and recruitment-dependent interaction strength. Ecological Monographs 69(3): 277-296.

Costa, J.E. 1988. Distribution, production, and historical changes in abundance of eelgrass (*Zostera marina* L.) in Southeastern MA. Ph.D. Thesis. Boston University. 395 p.

Dayton P.K. 1971. Competition, disturbance and community organization: the provision and subsequent utilization of space in a rocky intertidal community. Ecol Monogr 41:351-89.

Dayton, P.K. 1985. Ecology of kelp communities. Ann. Rev. Ecol. Syst. 16: 215-245.

Dean, T.A. and J.L. Bodkin. 2006. Sampling protocol for the nearshore restoration and ecosystem monitoring (N-REM) program. Exxon Valdez Restoration Project //0750. Draft Final Report. Exxon Valdez Restoration Office, Anchorage, AK.

Dean, T.A., J.L. Bodkin, A.K. Fukuyama, S.C. Jewett, D.H. Monson, C.E. O'Clair, and G.R. VanBlaricom. 2002. Food limitation and the recovery of sea otters in Prince William Sound. Mar. Ecol. Prog. Ser. 241:255-270.

Dean, T. A., L. Haldorson, D. R. Laur, S. C. Jewett, and A. Blanchard. 2000. The distribution of nearshore fishes in kelp and eelgrass communities in Prince William Sound, Alaska: associations with vegetation and physical habitat characteristics. Environmental Biology of Fishes 57: 271-287.

Dean, T. A., and S. C. Jewett. 2001. Habitat-specific recovery of shallow subtidal communities following the *Exxon Valdez* oil spill. Ecological Applications 11(5): 1456-1471.

Dean, T. A., S. C. Jewett, D. R. Laur, and R. O. Smith. 1996b. Injury to epibenthic invertebrates resulting from the Exxon Valdez oil spill. *In* proceedings of the *Exxon Valdez* oil spill symposium, (Rice, S.D., Spies, R.B., Wolfe, D.A., Wright, B.A. eds) Symposium. American Fisheries Society, Symposium 18, Bethesda, Maryland.

Dean, T. A., M. S. Stekoll, S. C. Jewett, R. O. Smith, and J. E. Hose. 1998. Eelgrass (*Zostera marina* L.) in Prince William Sound, Alaska: effects of the *Exxon Valdez* oil spill. Marine Pollution Bulletin 36(3): 201-210.

Dean, T. A., M. S. Stekoll, and R. O. Smith. 1996a. Kelps and Oil: The Effects of the *Exxon Valdez* Oil Spill On Subtidal Algae. *in* Proceedings of the *Exxon Valdez* oil spill symposium, (Rice, S.D., Spies, R.B., Wolfe, D.A., Wright, B.A. eds) Symposium. American Fisheries Society, Symposium 18, Bethesda, Maryland.

Driskell, W. B., A. K. Fukuyama, J. P. Houghton, D. C. Lees, A. J. Mearns, and G. Shigenaka. 1996. Recovery of Prince William Sound intertidal infauna from Exxon Valdez oiling and shoreline treatments, 1989 through 1992 . (Rice, S.D., Spies, R.B., Wolfe, D.A., Wright, B.A. eds) Symposium. American Fisheries Society, Symposium 18, Bethesda, Maryland.

Drew, G. S., S. G. Speckman, J. F. Piatt, J. M. Burgos and J. L. Bodkin. 2008. Survey design considerations for monitoring marine predator populations in Glacier Bay, Alaska: Results and post-hoc analyses of surveys conducted in 1999-2003. USGS Administrative Report. 128pp.

Earnst, S.L., R.A. Stehn, R.M. Platte, W.M. Larned, and E.J. Mallek. 2005. Population size and trend of yellow-billed loons in northern Alaska. The Condor. 107:289-304.

Estes, J. A., and D. O. Duggins. 1995. Sea Otters and Kelp Forests in Alaska: Generality and Variation in a Community Ecological Paradigm. Ecological Monographs. 65. (1.): 75-100.

Estes, J. A., and J. F. Palmisano. 1974. Sea Otters: Their Role in Structuring Nearshore Communities. Science. 185.: 1058-1060.

Estes, J.A., R.J. Jameson, and A.M. Johnson. 1981. Food selection and some foraging tactics of sea otters. J.A. Chapman, and D.Pursley (Eds.). The worldwide furbearer conference proceedings. 1981. University of Maryland Press, Bethesda, MD.

Estes, J.A., M.T. Tinker, T.M. Williams, and D.F. Doak. 1998. Killer whale predation on sea otters linking coastal with oceanic ecosystems. Science 282:473-476.

Esler, D, K.A. Trust, B.E. Ballachey S.A. Iverson, T.L. Lewis, D.J. Rizzolo, D.M. Mulcahy, A.K. Miles, B.R. Woodin, J.J. Stegeman, J.D. Henderson, and B.W. Wilson. 2010. Cytochrome P4501A biomarker indication of oil exposure in harlequin ducks up to 20 years after the Exxon Valdez oil spill. Environmental Toxicology and Chemistry 29:1138–1145.

Esler, D,. B.E. Ballachey, K.A. Trust, S.A. Iverson, J.A. Reed, A.K. Miles, J.D. Henderson, B.R. Woodin, J.J. Stegeman, M.McAdie, D.M. Mulcahy, and B.W. Wilson. 2011. Cytochrome P4501A biomarker indication of the timeline of chronic exposure of Barrow's goldeneyes to residual Exxon Valdez oil. Marine Pollution Bulletin 62:609–614.

Feder H.M., and Jewett S. C. 1987. The subtidal benthos. In: Hood, D. W., Zimmerman, S. T. (eds) The Gulf of Alaska. Physical environment and biological resources, Ocean Assessment Div., Alaska Office, US Minerals Management Service, Alaska OCS Region, MMS 86-0095 US Govt. Printing Office, Washington, DC.

Feder, H. M., and G. E. Kaiser. 1980. Intertidal biology. *In*: J.M. Colonell (ed.), Port Valdez, Alaska: Environmental studies 1976-1979. University of Alaska, Institute of Marine Science, Fairbanks.

Ford, R.J., M.L. Bonnell, D.H. Varoujean, G.W. Page, H.P. Carter, B.E. Sharp, D. Heinemann, and J.L. Casey. 1996. Pages 684-711. *In*: S.D. Rice, R.B. Spies D.A. Wolfe and B.A. Wright (Eds). Proceedings of the *Exxon Valdez* Oil Spill Symposium. American Fisheries Society Symposium 18.

Foster, M.S and D.R. Schiel. 1985. The ecology of giant kelp forests in California: a community profile. U.S. Fish Wildlife Service Biol. Rep. 85. U.S. Department of Interior, Washington D.C.

Fukuyama, A.K., G. Shigenaka and R.Z. Hoff. 2000. Effects of residual Exxon Valdez oil on intertidal Protothaca staminea: Mortality, growth, and bioaccumulation of hydrocarbons in transplanted clams. Marine Pollution Bulletin 40(11):1042-1050.

Gaines, S., S. Brown, and J. Roughgarden. 1985. Spatial variation in larval concentration as a cause of spatial variation in settlement for the barnacle, *Balanus glandula*. Oecologia. 67(2): 267-272.

Gaines, S. D., and J. Roughgarden. 1985. Larval settlement rates: A leading determinant of structure in an ecological community of the marine intertidal zone. Proceedings of the National Academy of Science, USA 82(11): 3707-3711.

Goudie, R.I. and C.D. Ankey. 1986. Body size, activity budgets, and diets of sea ducks wintering in Newfoundland. Ecology 67:1475-1482.

Harper, J.R., and M.C. Morris. 2004. ShoreZone mapping protocol for the Gulf of Alaska (ver 1.0) CORI Project: 02-33 EVOS Project: 030641. Exxon Valdez Trustee Council, Anchorage, AK.

Haven, S. B. 1971. Effects of land-level changes on intertidal invertebrates, with discussion of post earthquake ecological succession. In: The great Alaska earthquake of 1964. Report to National Academy of Sciences, Washington, DC. Pp 82-128.

Highsmith, R.C., M.S. Stekoll, W.E. Barber, L. McDonald, D. Strickland, and W.P. Erickson. 1994. Comprehensive assessment of coastal habitat. *Exxon Valdez* oil spill state/federal natural resource damage assessment. Final report of coastal habitat study 1A. *Exxon Valdez* Oil Spill Trustee Council, Anchorage.

Hines, J.E., T. Boulinier, Nichols, J.D., J.R. Sauer, and K.H. Pollock. 1999. COMDYN: Software to study dynamics of animal communities using a capture-recapture approach. Bird Study 46 (suppl.):s209-217.

Houghton, J.P., R.H. Gilmour, D.C. Lees, W.B. Driskell, and S.C. Lindstrom. 1996. Evaluation of the condition of Prince William Sound shorelines following the Exxon Valdez oil spill and subsequent shoreline treatment. Volume 1. 1994 Biological Monitoring Survey. NOAA Technical Memorandum NOS ORCA 91. National Oceanic and Atmospheric Administration, Seattle, WA.

Hubbard, J. D. 1971. Distribution and abundance of intertidal invertebrates at Olsen Bay in Prince William Sound, Alaska, one year after the 1964 earthquake. In: The great Alaska earthquake of 1964. Report to National Academy of Sciences, Washington, DC. Pp 137-157.

Irons, D.B., S.J. Kendall, W.P. Erickson, L.L. McDonald, and B.K. Lance. 2000. Nine Years after the Exxon Valdez Oil Spill: Effects on Marine Bird Populations in Prince William Sound, Alaska. The Condor 102: 723-737.

IUCN 2002. IUCN Red list of threatened species. – Available on the web at http://www.redlist.org.

Iverson, S.A. and D. Esler. 2010. Harlequin Duck population injury and recovery dynamics following the 1989 Exxon Valdez oil spill. Ecological Applications 20(7):1993-2006.

Jamieson, G.S., E.D. Grosholz, D.A. Armstrong , and R.W. Elner. 1998. Potential ecological implications from the introduction of the European green crab, *Carcinus maenas* (Linneaus), to British Columbia, Canada, and Washington, USA. Journal of Natural History 32:1587-1598.

Jewett, S. C., and T. A. Dean. 1977. The effects of the *Exxon Valdez* oil spill on shallow subtidal eelgrass communities in Prince William Sound, Alaska 1990-95. The effects of the *Exxon Valdez* oil spill on shallow subtidal eelgrass communities in Prince William Sound, Alaska 1990-95. Final Report to the *Exxon Valdez* Oil Spill Trustee Council, Anchorage.

Jewett, S. C., T. A. Dean, R. O. Smith, and A. Blanchard. 1999. The *Exxon Valdez* oil spill: Impacts and recovery in the soft-bottom benthic community in and adjacent to eelgrass beds. Marine Ecology Progress Series 185: 59-83.

Küchenhoff, H. and R.J. Carroll. 1997. Segmented regression with errors in predictors: Semi-parametric and parametric methods. Statistics in Medicine 16:169 - 188.

Kvitek, R.G., J.S. Oliver, A.R. DeGange, and B.S. Anderson. 1992. Changes in Alaskan soft-bottom prey communities along a gradient in sea otter predation. Ecology 73(2): 413-428.

Lees, D.C. and W.B. Driskell. 2006. Intertidal Reconnaissance Survey to Assess Composition, Distribution, and Habitat of Marine/Estuarine Infauna in Soft Sediments in the Southwest Alaska Network. Final Report. National Park Service-Southwest Alaska Network. Anchorage, AK. 51 pgs.

Lewis, J. 1996. Coastal benthos and global warming: strategies and problems. Marine Pollution Bulletin 32:698-700.

Lowry, L. L., and J. L. Bodkin. 2005. Marine Mammals. *In* The Gulf of Alaska: Biology and Oceanography. P.R. Mundy (ed.). Alaska Sea Grant College Program, University of Alaska Fairbanks. Pp 96-116.

Lukas, P.M., W.L. Thompson, W.L. Kendall, W.R. Gould, P.F. Dougherty, K.P. Burnham, and D.R. Anderson. 2007. Concerns regarding a call for pluralism of information theory and hypothesis testing. J. Appl. Ecol. 44:456-460.

Marsh, C. P. 1986. The Impact of avian predators on high intertidal limpet populations. J. Exp. Mar. Biol. Ecol. 104: 185-201.

McCulloch, C. E., S.R. Searle, and J.M. Neuhaus. 2008. Generalized, Linear and Mixed Models. Wiley, Hoboken, 384p.

McDonald, T. 2005. The users guide: GRTS for the Average Joe: A GRTS Sampler for Windows. http://www.west-inc.com/computer.php

McRoy, C. P. 1968. The distribution and biogeography of *Zostera marina* (Eelgrass) in Alaska. Pacific Science 22(4): 507-513.

McRoy, C. P. 1970. Standing stocks and other features of eelgrass (*Zostera marina*) populations on the coast of Alaska. Journal Fisheries Research Board of Canada 27(10): 1811-1821.

Monson, D.H., D.F. Doak, B.E. Ballachey, A. Johnson, and J.L. Bodkin. 2000. Long-term impacts of the *Exxon Valdez* oil spill on sea otters, assessed through age-dependent mortality patterns. Proc. Natl. Acad. Sci. USA 97:6562-6567.

Monson, D.H., D.F. Doak, B. E. Ballachey, and J.L. Bodkin. 2011. Effect of the Exxon Valdez oil spill on the sea otter population of Prince William Sound, Alaska: Do lingering oil and source-sink dynamics explain the long-term population trajectory? Ecological Applications 21(8):2917-2932.

Mortenson, D.C. 2006. Data management plan: Southwest Alaska Network Inventory and Monitoring Plan. Report to the National Park Service, Anchorage Alaska

Mundy, P. R. (editor). 2005. The Gulf of Alaska: Biology and Oceanography. Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks, Alaska.

Neushul, M. 1981. Historical review of kelp beds in Southern California. Report to Southern California Edison Co., Rosemead, CA.

NRC. 1971. The great Alaskan earthquake of 1964. National Research Council. National Academy Press, Washington, D. C.

Nichols, J.D., T. Boulinier, J.E. Hines, K.H. Pollock, and J.R. Sauer. 1998. Estimating rates of local species extinction, colonization, and turnover in animal communities. Ecol. Appl. 8:1213-1225.

Nichols, J.D. and B.K. Williams. 2006. Monitoring for conservation. Trends in Ecol. Evol. 21:668-673.

Nichols, J.D., M.C. Runge, and W.L. Kendall. 2007. Proposal: Structured decision making, ecological thresholds and the establishment of management trigger points. Proposal submitted to the National Park Service, Washington D.C.

North, W. J. 1964. An Investigation of the effects of discharged wastes on kelp. *In* Report to the California State Water Quality Control Board. Publication No. 26. Sacramento ,Ca. 121p.

Nybakken, J. W. 1969. Pre-earthquake intertidal ecology of Three Saints Bay, Kodiak Island, Alaska: *in* Biological Papers of the University of Alaska, Fairbanks.

O'Clair C.E., and S.D. Rice. 1985. Depression of feeding and growth rates of the seastar (*Evasterias troschelii*) during long term exposure to water soluble fractions of crude oil. Marine Biol. 84: 331-340.

O'Clair, C.E. and S.T. Zimmerman. 1987. Biogeography and ecology of intertidal and shallow subtidal communities. In: D.W. Hood and S.T. Zimmerman (eds.) The Gulf of Alaska: physical environment and biological resources. National Oceanic and Atmospheric Administration. Anchorage p. 305-344.

O'Clair, R.M., and C.E. O'Clair. 1998. Southeast Alaska's Rocky Shores: *Animals*. Plant Press, Auke Bay, Alaska. 564p.

O'Clair, C.E., J Milstein and M. Lindeberg. 1999. Mesoscale differences in mussel, *Mytilus trossulus*, population structure in Prince William Sound, Alaska in relation to oiling history and predation intensity. Appendix SO-5 In: Holland-Bartels, L.E. (ed.) Mechanisms of impact and potential recovery of nearshore vertebrate predators following the 1989 Exxon Valdez oil spill. Restoration Project 95025-99025 Final Report. Report to the Exxon Valdez Trustee Council. Anchorage.

O'Connor, T.P. 1996. Trends in chemical concentrations in mussels and oysters collected along the U.S. Coast from 1986 to 1993. Mar. Env. Res. 41:183-200

Oakley, K.L, L.P. Thomas, and S.G. Fancy. 2003. Guidelines for long-term monitoring protocols. Wildlife Society Bulletin 31:1000-1003.

Paine, R.T. 1974. Intertidal community structure: experimental studies on the relationship between a dominant competitor and its principal predator. Oecologica 15:93-120

Paine, R.T. 1977. Controlled manipulations in the marine intertidal zone, and their contributions to ecological theory. Pp 245-270. In C.E. Goulden (Ed.) The Changing Scenes in the Natural Sciences. Philadelphia, Academy of Natural Sciences. Philadelphia

Paine R.T, J.C. Castillo, and J Cancino. 1985. Perturbation and recovery of starfish dominated intertidal assemblages in Chile, New Zealand, and Washington State. Amer. Natur. 125:679-691.

Peterson, C.H. 1993. Improvement of environmental impact by application of principles derived from manipulative ecology: Lessons from coastal marine case histories. Australian Journal of Ecology. 18.:21-52.

Peterson, C.H. 2001. The Exxon Valdez oil spill in Alaska: acute, indirect and chronic effects on the ecosystem. Advances in Marine Biology 39:1-103.

Peterson, C. 2005. Nearshore benthic communities. *In* The Gulf of Alaska: Biology and Oceanography P R. Mundy (ed). The Gulf of Alaska: Biology and Oceanography. Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks, Alaska.

Peterson, C.H., S.D. Rice, J.W. Short, D. Esler, J.L. Bodkin, B.E. Ballachey, and D.B. Irons. 2003. Long-term ecosystem response to the *Exxon Valdez* oil spill. Science 302:2082-2086.

Petraitis, P.S. and S.R. Dudgeon. 2004. Detection of alternate stable states in marine communities. J. Exp. Mar. Biol. Ecol. 300:343-371.

Power, M. E., D. Tilman, J. A. Estes, B. A. Menge, W. J. Bond, L. S. Mills, G. Daily, J. C. Castilla, J. Lubchenco, and R. T. Paine. 1996. Challenges in the quest for keystones. BioScience 46(8): 609-620.

Research Planning Institute, Inc (RPI). 1983a. Sensitivity of coastal environments and wildlife to spilled oil, Prince William Sound, Alaska: an atlas of coastal resources. Report to NOAA (National Oceanic and Atmospheric Administration) Office of Oceanography and Marine Services Seattle.

Research Planning Institute, Inc (RPI). 1983b. Sensitivity of coastal environments and wildlife to spilled oil, Shelikof Strait, Alaska: an atlas of coastal resources. Report to NOAA (National Oceanic and Atmospheric Administration) Office of Oceanography and Marine Services Seattle.

Research Planning Institute, Inc (RPI). 1985. Sensitivity of coastal environments and wildlife to spilled oil, Cook Inlet/Kenai Peninsula, Alaska: an atlas of coastal resources. Report to

NOAA (National Oceanic and Atmospheric Administration) Office of Oceanography and Marine Services Seattle.

Research Planning Institute, Inc (RPI). 1986. Sensitivity of coastal environments and wildlife to spilled oil, Southern Alaska Peninsula , Alaska: an atlas of coastal resources. Report to NOAA (National Oceanic and Atmospheric Administration) Office of Oceanography and Marine Services Seattle.

Riedman, M. L., and J. A. Estes. 1990. The Sea Otter (Enhydra lutris): Behavior, Ecology, and Natural History. US Fish and Wildlife, National Technical Service. 90 (14).

Robards, M., J. F. Piatt, A. Kettle, and A. Abookire. 1999. Temporal and geographic variation in fish populations in nearshore and shelf areas of lower Cook Inlet. Fisheries Bulletin. 97(4): 962-977.

Robertson, G. J., and R. I. Goudie. 1999. Harlequin duck: the birds of North America. The American Ornithologists Union, Washington, DC, and the Academy of Natural Sciences, Philadelphia

Rosenthal, R. 1980. Shallow water fish assemblages in the northeastern Gulf of Alaska: habitat evaluation, species composition, abundance, spatial distribution and tropic interaction. Prepared for the National Oceanic and Atmospheric Administration, Outer Continental Shelf Environmental Assessment Project Office, Juneau, Alaska.

Rosenthal, R. J., D. C. Lees, and T. M. Rosenthal. 1977. Ecological assessment of sublittoral plant communities in northern Gulf of Alaska. in Final Report to National Marine Fisheries Service (NMFS), Auke Bay Laboratory, Juneau, Alaska .

SAS Institute. 2000. SAS/SYSTAT user's guide. Vol. 2. version 8. SAS Institute, Inc. Cary, N.C.

Sagarin R.D. , Barry J.P. , Gilman S.E. , and Baxter C.H. 1999. Climate related changes in an intertidal community over short and long time scales. Ecological Monographs 69:465-490.

Seber, G.A.F. and C.J. Wild. 1989. Non-Linear Regression. Wiley, Hoboken.

Schiel, D.R. and D.I. Taylor. 1999. Effects of trampling on a rocky intertidal algal assemblage in southern New Zealand. J. Exp. Mar. Biol. & Ecol. 235:213-235.

Schoch, K., G. Eckert, and T. Dean. 2002. Long term monitoring in the nearshore: Designing a program to detect change and determine cause. GEM Project 02395. Report to the Exxon Valdez Oil Spill Trustee Council, Anchorage.

Seed, R. and T.H. Suchanek. 1992. Population and community ecology of *Mytilus*. Pages 87-169 In: Gosling (ed.) The mussel, *Mytilus*: ecology, physiology, genetics, and culture. Elsiver, Amsterdam. P 13-65.

Short, J.W., J.M. Maselko, M.R. Lindeberg, P.M. Harris, and S.D. Rice. 2006. Vertical distribution and probability of encountering intertidal Exxon Valdez oil on shorelines of three embayments within Prince William Sound, Alaska. Environmental Science and Technology 40(12):3723-3729.

Short, F.T. and S. Wyllie-Echeverria.1996. Natural and human-induced disturbance of seagrasses. Environmental Conservation 23: 17-27.

Skalski, J.R., D.A. Coats, and A.K. Fukuyama. 2001. Criteria for Oil Spill Recovery: A Case Study of the Intertidal Community of Prince William Sound, Alaska, Following the Exxon Valdez Oil Spill. Environmental Management 28:9-18.

Simenstad, C. A., W. J. Kinney, S. S. Parker, E. O. Salo, J. R. Cordell, and H. Buechner. 1980. Prey community structure and trophic ecology of outmigrating juvenile chum and pink salmon in Hood Canal Washington: A synthesis of three years' studies, 1977-1979. *In* Fisheries Research Institute Report FRI-UW-8026 University of Washington, College of Fisheries, Seattle, Washington.

Sousa, W. P. 1979. Experimental investigations of disturbance and ecological succession in a rocky intertidal algal community. Ecological Monographs. 49.:227-254.

Spies R.B., S. D. Rice, D. A. Wolfe, and B. A. Wright. 1996. The effects of the *Exxon Valdez* Oil Spill on the Alaskan coastal environment. *In* Proceedings of the *Exxon Valdez* oil spill symposium. Am Fish Soc Symp 18.

Stevens, D.L. and A.R. Olsen. 2004. Spatially Balanced Sampling of Natural Resources. Journal of the American Statistical Association 99:262-278.

Sundberg, K., L. Deysher, and L. McDonald. 1996. Intertidal and Supratidal Site Selection Using a Geographical Information System. Pages 167–176. *in*: S.D. Rice, R.B. Spies D.A. Wolfe and B.A. Wright eds. Proceedings of the *Exxon Valdez* Oil Spill Symposium. American Fisheries Society Symposium 18.

Trowbridge, C. 1995. Prince William Sound management area 1994 shellfish annual management report. Alaska Department of Fish and Game, Anchorage.

Tyre, A.J., B. Tenhumberg, S.A. Field, D. Niejalke, K. Parris, and H.P. Possingham. 2003. Improving precision and reducing bias in biological surveys: estimating false-negative error rates. Ecological Applications 13: 1790-1801

Valiela, I. 2006. Global Coastal Change. Blackwell Publishing. Malden, MA. 368 p.

VanBlaricom, G. R. 1988. Effects of foraging by sea otters on mussel-dominated intertidal communities. Pages 48-91: *In*: The Community Ecology of Sea Otters, G.R. Vanblaricom and J.A. Estes eds. Springer-Verlag, Berlin, Germany 247 pp.

Vermeer, K. 1983. Diet of the harlequin duck in the Strait of Georgia, British Columbia. The Murrelet: 54-57.

Vermeer, K. 1982. Food and distribution of three *Bucephala* species in British Columbia waters. Wildfowl 33: 22-30.

Ward, D.H., C.J. Markon, and D.C. Douglas. 1997. Distribution and stability of eelgrass beds at Izembek Lagoon, Alaska. Aquatic Botany 58:229-240.

Webster, J. D. 1941. Feeding habitats of the black oyster-catcher. Condor 43: 175-180.

Appendix A

Possible agents of change in nearshore systems of the Gulf of Alaska over the next several decades, their physical effects, biological effects, and temporal and spatial scales on which impacts are likely to occur.

Agent of Change	Physical Effect	Biological Effect	Temporal and Spatial Scale[1]
Natural			
ENSO - El Nino	• Temperature increase • Decreased upwelling • Increase storm activity	• Decrease in primary production • Northerly range extension of southern species • Increase in some diseases	Years/Region
ENSO – La Nina	• Temperature decrease • Increased upwelling	• Southerly range extension of northern species • Increase in primary production •	Years/Region
PDO	• Temperature increase (in warm cycle) • Decreased upwelling (in warm cycle)	• Decrease in primary production • Northerly range extension of southern species • Increase in some diseases	Decades/Region
Extreme cold	• Freezing in intertidal • Extreme cold air temp	• Death of Inverts/algae and some vertebrates	Days (though effects may last years) /Area (with greater effects in northerly exposures)
Extreme heat	• Heat/desiccation in intertidal (especially if coincident with spring tide)	• Death of inverts/algae	Days (though effects may last years) /Area (with greater effects in southerly exposures)
Storms	• Waves/debris increase • Salinity decrease	• Death of inverts/algae and some vertebrates	Days (though effects may last years) /Area (with greater effects in more exposed locations, locations with movable substratum, or nearer stream mouths)
Disease	•	• Increased death rate or reduced reproductive rate	Largely unknown
Earthquakes	• Uplift or downthrust • Sediment shifting and shifting of stream	• Killing of inverts and algae	Minutes/Hours (though effects may last years) /Area (with greater effects in areas of

Agent of Change	Physical Effect	Biological Effect	Temporal and Spatial Scale[1]
	mouths		greatest uplift/downthrust
Volcanoes	• Increased sedimentation in intertidal	• Smothering of inverts and algae	Minutes/Hours (though effects may last years) /Area (with greater effects in areas most exposed to ash
Glacial activity	• Increased / decreased sedimentation and calving	• Smothering of inverts and algae (on advance) or increase in exposed bottom/intertidal inverts and algae and decreased glacial feeding by birds (on retreat)	Decades/Location or Sites
Anthropogenic	•	•	
Global warming	• Increased temperature • Increased UV radiation • Reduced salinity	• Northerly shift in species distribution • Reduced photosynthesis of kelp • Reduction in marine stenohaline spp.	Years/Region
Ocean acidification	• Reduction in pH of ocean waters	• Reduction in abundance of mollusks, echinoderms, and other organisms that rely on calcium carbonate for skeletons	Years/Region
Introduction of exotic spp.	• None	• Reduction in abundance of competitors/prey	Years/Area
Fishing	• None	• Reduction in targeted stocks • Reduction in predators of those stocks, possible habitat destruction	Years/Area or Location
Aquaculture (especially intertidal clam)	• None	• Intertidal habitat loss • Reduction in intertidal inverts/algae with possible reduction in their predators	Years/Area or Location
Coastal development	• Increased sedimentation and eutrophication • Introduction of contaminants	• Reduction in fish spawning habitat • Reduction in inverts and algae intolerant to stress	Years/Sites

Agent of Change	Physical Effect	Biological Effect	Temporal and Spatial Scale[1]
		• Increases in stress tolerant spp. • Increased contaminant levels in animals • Increased death rate or reduced reproductive rate especially in higher trophic levels.	
Recreational use	• None	• Disturbance to mammals/birds • Entanglement of birds/mammals with trash • Reduction in intertidal inverts/algae due to trampling	Years/Sites
Watershed development	• Increased sedimentation • Increased eutrophication • Introduction of contaminants	• Reduction in fish spawning habitat • Reduction in inverts and algae intolerant to stress • Increases in stress tolerant spp. • Increased contaminant levels in animals • Increased death rate or reduced reproductive rate especially in higher trophic levels.	Years/Sites (especially at stream or river mouths)
Contamination from distant sources	• Increased levels of metals and other chemicals	• Increased contaminant levels in animals • Increased death rate or reduced reproductive rate especially in higher trophic levels.	Years/Region or Areas
Logging activity	• Increased sedimentation and eutrophication • Introduction of contaminants	• Reduction in fish spawning habitat • Reduction in inverts and algae intolerant to stress • Increases in stress tolerant spp. • Increased contaminant levels in animals • Increased death rate or reduced reproductive rate especially in higher trophic levels.	Years/Sites

Agent of Change	Physical Effect	Biological Effect	Temporal and Spatial Scale[1]
Oil or chemical spills	• Increased levels of contamination	• Reduction in inverts and algae intolerant to stress • Increase in stress tolerant spp. • Increased contaminant levels in animals • Increased death rate or reduced reproductive rate especially in higher trophic levels.	Days (although impacts may last years or decades) /locations or sites

[1] Definition of spatial scales (with approximate shoreline extents)

Region – Gulf of Alaska (1,000 plus km)

Area – Prince William Sound, Kenai Peninsula, Kodiak archipelago, and Alaska Peninsula) – (200 km)

Location – Subareas on the order of Western Prince William Sound 50-100 km

Site - E.g. Herring Bay, Orca Inlet, Jakalof Bay, etc. (5-10 km)

Spot – 10s to 100s of m

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